WIND LENS ENERGY RECOVERY SYSTEM

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ABSTRACT

The exhaust air energy recovery wind turbine generator is an on-site clean energy generator that utilizes the advantages of discharged air which is strong, consistent and predictable. Cooling tower is one of the most common exhaust air systems that are used to dissipate heat from power generation units, water-cooled refrigeration, air conditioning and industrial processes. It is a device used to transfer waste heat to the atmosphere; large office buildings, hospitals and schools typically install one or more cooling towers for the building ventilation system. The idea of this work is to develop an energy recovery system by installing a shrouded wind turbine at the outlet of the cooling tower to generate electricity from the wasted discharged air. The wind power developed from a wind turbine is proportional to the cubic power of velocity. Hence a large increase in power output can be obtained with a slight increase in velocity. This principle is used in shrouded wind turbine. A flanged diffuser shroud is used to create pressure gradient which results in an increase in the approaching wind velocity. In our experiment, we had found that at a distance 92cm from the center of the fan, had a free stream velocity of 7 m/s and with shroud the velocity of intake air has been increased to 8 m/s. The available wind power increased from 13.58 W without shroud at a free stream velocity of 7 m/s to 20.27 W with shroud at a velocity of 8 m/s which shows a definite increase in velocity and hence available power by 66.99%. Thus, energy saved by this system can be fed into main grid and this is a promising wind power alternative for areas with low wind velocity where bare wind turbines are not practical.

Keywords: Cooling Tower, Shroud, Airfoil.
1. INTRODUCTION

The energy crisis is one of the major problems affecting the countries worldwide. One of the methods to overcome energy crisis is to utilize the energy available effectively and also to reduce or recover energy that is being wasted. The fact that non-renewable sources of energy cause pollution and the increased ecological hazards and their rate of depletion has necessitated the use of non-conventional renewable sources and also to adopt the methods of energy recovery. Energy recovery includes any technique or method of minimizing the input of energy to an overall system by the exchange of energy from one sub-system of the overall system with another. The energy can be in any form in either subsystem. Energy recovery systems harvest the output power and providing this as input power to the same or another process.

Exhaust air energy recovery system is a relatively new field of energy recovery system which converts exhaust air energy into usable electricity. The energy can be stored and released during peak demand. It reduces point-of-use consumption by 15% or more and has short term return on investment. It has low maintenance and can be easily integrated with an electronic control system. Here the energy capture is done by a wind turbine which is coupled to a generator and can be horizontally or vertically installed at site.

Cooling tower is one of the most common exhaust air systems that is used to dissipate heat from power generation units, water-cooled refrigeration, air conditioning and industrial processes. It is a device used to transfer waste heat to the atmosphere; large office buildings, hospitals and schools typically install one or more cooling towers for the building ventilation system. In the journal “Exhaust Air and Wind Energy Recovery System for Clean Energy Generation” by Chong Sean and Tiah Chai Ching,[1] the cooling tower exhaust air was recorded to be 18 m/s, which is sufficient for wind power generation.

Wind power is proportional to the cubic power of wind velocity. Therefore, a large increase in output is brought about if it is possible to create even a slight increase in the velocity of the approaching wind to a wind turbine. If we can increase the wind speed by utilizing the fluid dynamic nature around a structure or topography, namely if we can concentrate the wind energy locally, the power output of a wind turbine can be increased substantially. For this purpose, Yuji Ohy and Takashi Karasudani [4] have developed a diffuser-type structure that is capable of collecting and accelerating the approaching wind. They have devised a diffuser shroud with a large brim that is able to increase the wind speed from approaching wind substantially by utilizing various flow characteristics, ie, the generation of low pressure region by vortex formation, flow entrainment by vortices and so on, of the inner or peripheral flows of a diffuser shroud equipped with a brim. As a result, the shrouded wind turbine equipped with a brimmed diffuser demonstrated power augmentation of 4–5 as compared to a corresponding bare wind turbine.

The purpose of this work is to develop an energy recovery system by installing a shrouded wind turbine at the outlet of the cooling tower to generate electricity from the wasted discharged air.

2. LITERATURE REVIEW

W.T Chong and S.Y Yip [5] conducted experiments on energy recovery from cooling towers. Two vertical axis wind turbines (VAWTs) in cross-wind orientation were integrated with an enclosure, and installed at the outlet of a cooling tower to harness the discharged wind for electricity generation. Based on the discharged air wind speed profile, the turbines are positioned so that the highest wind speed is facing the positive torque sector of the wind turbines. To enhance the performance, the VAWTs are surrounded by an enclosure. The enclosure is constructed with the combination of a diffuser, several guide-vanes and safety grills. The diffuser plays the role of concentrating and accelerating the approaching wind to the wind turbine. The resulting sub-
atmospheric pressure within the diffuser draws more air through the blade plane, and hence more power can be generated compared to a turbine without diffuser of the same rotor blade diameter. Ken-ichi Abe, Yuji Ohya[7] carried out numerical investigations for flow fields around flanged diffusers to develop small type wind turbines under 1.5 kW. Comparison of the computed results with the corresponding experimental data is done. Furthermore, by processing the computational results, the input power coefficient is estimated under various conditions of diffuser opening angle and loading coefficient. It is shown that the performance of a flanged diffuser strongly depends on the loading coefficient as well as the opening angle because it greatly affects the nature of the separation appearing inside the diffuser. Their present investigation suggests that the loading coefficient for the best performance of a flanged diffuser is considerably smaller than that for a bare wind turbine.

Yuji Ohya and Takashi Karasudani [4] designed a shrouded wind turbine that is equipped with a brimmed diffuser came. They call it the “wind-lens turbine”. Next they added an appropriate structure for entrance, called an inlet shroud, to the entrance of the diffuser with a brim. The inlet shroud makes wind easy to flow into the diffuser. Viewed as a whole, the collection-acceleration device consists of a venturi-shaped structure with a brim. The plate forms vortices behind it and generates a low-pressure region behind the diffuser. Accordingly, the wind flows into a low-pressure region; the wind velocity is accelerated further near the entrance of the diffuser.

B Rasuo and M Adzic [3] made a comparative study on three different airfoils namely NACA 63(2)215, FFA-W3-211 and A-Airfoil on CFD software fluent and measured their performances on air turbines. The drag and lift curves for each airfoil was plotted. Their aim was to design airfoils that would increase the overall efficiency of wind turbines. NACA 63(2)215 is an airfoil from the 6th series of NACA laminar wing section family. Maximum relative thickness is 15%, located at 35% of the chord length. The experimental data was measured in low-turbulence pressure tunnel at NASA. Computational mesh was done in Fluent’s mesh tool Gambit. The resolution of the mesh is greater in regions where greater computational accuracy was needed, such as the region of the leading edge and the trailing edge wake. The mesh consists of 11970 quadrilateral cells, of which 146 is on the airfoil. Reynolds number for the experiments and simulations is Re=3X10^6 and turbulence intensity is 0.07%. A fully turbulent flow solution was used in Fluent, where k-ω SST model was used for turbulent viscosity. Calculations were done for the “linear” region, i.e. for angles of attack ranging from -2 to 6 degrees, due to greater reliability of both experimental and computed values in this region. They found out that maximum lift was produced for a 6 degree angle of attack for NACA 63(2)215.

3. DEVELOPMENT OF ENERGY RECOVERY SYSTEM

3.1 Airfoil Blade

From the article “Design of Airfoils for Wind Turbine Blades” by B. Rasuo and M Adzic [3] we selected the NACA 63(2)215 airfoil profile among the three profiles studied by them, due to its effectiveness, simple geometry and ease of fabrication. We didn’t focus on blade design but manufactured the blade according to the profile as given in the journal. The material we used to manufacture the blade is acrylic or PMMA. (Polymethyl methacrylate) (PMMA) is a transparent thermoplastic, often used as a lightweight or shatter-resistant alternative to glass. Acrylic fibers have three main properties. They have high bulk, are good heat retention and fastness to light and they also have good shape retention, durability and quick dry qualities
3.2 Hub

The hub to which the blades are attached is made of softwood. It has provision for inserting the spindle of the motor and is fixed together using glue. Softwood has the properties of being less expensive compared to hardwood. It is strong in tension but weak in shear. It is easier to machine. The three blades are thus fabricated are attached to the provisions given in the hub by means of glue. The parameters required in fabricating such blades are: Expected free stream velocity - 6m/s. Blade radius - 15cm. Angle of attack - 6°. Blade material – Acrylic. Hub diameter – 6.6cm. Hub material – Softwood.

3.3 Wind Lens (shroud)

Based on design, which gives power output than a bare wind turbine by Yuji Ohya and Takashi Karasudani [4] we fabricated the same with a throat diameter of 30cm with all other dimensions relative to the throat in a metal engineering workshop. We have taken 30cm diameter because this is a scaled down model of the actual turbine that is to be integrated with the cooling tower and also the diameter of fan available for the experiment is 45cm, so the turbine diameter should be equal to or less than this fan diameter. A circular clamp is fitted near the throat of the shroud to bear the generator. It was so made that there is least obstruction to flow of air. The dimensions of the shroud are based on design, which gives power output than a bare wind turbine by Yuji Ohya and Takashi Karasudani [4] are described below. All dimensions are relative to the throat diameter (30cm).
L = 1.25 D = 37.5cm

Ls = 0.75 L = 28.125cm

Dh = 0.22 D = 6.6cm h = 0.5D = 15cm

φ = 12φ U∞ = 6 m/s(approx) Material used: G.I sheet with 20 gauge thickness

Fig 3: Shroud made of GI sheet

3.4 Generator

Here a D.C stepper motor which was converted into an A.C generator was selected due to its low starting torque and small size so that it obstructs little amount of air.

4. EXPERIMENTAL DEMONSTRATION

A scaled down model of the cooling tower draft fan was recreated using an ALMONARD 90 W pedestal fan. The energy recovery turbine was placed in front of the fan and due to experimental limitations; we could not recreate the enclosure of a cooling tower. The setup is a horizontal axis wind turbine. The power recovered with and without the wind lens was compared in the experiment. The shroud was kept as close as possible to the fan to obtain the negative pressure gradient effect. This distance was determined by trial and error so that we could harness maximum energy from the fan without affecting the mass flow rate and fan power requirement. First, we kept the shroud at 182.5cm, then 133cm, 111cm and 92cm and we fixed 92cm as our axial distance from the fan which have sufficient shroud effect as well as good free stream velocity. The experiment was conducted with and without shroud on the fixed axial distance. There is an electrical circuit associated for doing the load test on the turbine so that we can plot the Cpvs TSR curve.
5. ELECTRICAL CIRCUIT

An alternator of 12 volts was mounted at the center of shroud. A rotor having three blades of NACA profile was fixed to the alternator shaft. An ammeter, voltmeter and port resistor were connected to alternator as shown in the circuit diagram. The whole arrangement i.e.; without shroud was placed in front of the fan recreating the draft fan of the cooling tower. The tip speed ratio was varied by varying the resistance of the port resistor. For each tip speed ratio corresponding voltage and current was measured using a multimeter. The blade speed was measured using a digital tachometer. Velocity of free stream was measured using vane type anemometer. The same procedure was repeated with shroud. By knowing voltage and current, the output power can be calculated. From the power output, the power coefficient can be calculated. The calculated power coefficients for both the arrangements are compared and the plot between the Cp and TSR is plotted.

6. RESULTS AND DISCUSSION

As mentioned in the experiment demonstration, the experiment is conducted and the best position of the shroud and the assembly is found out and we can see a boost in air flow without affecting the overall power consumption of the fan.
6.1 Best position of shroud

Table 1: Best position of shroud

<table>
<thead>
<tr>
<th>SL NO</th>
<th>FAN I/P (W)</th>
<th>AIR INTAKE VELOCITY (m/s) WITH SHROUD</th>
<th>AXIAL DISTANCE FROM FAN (CM)</th>
<th>FREE STREAM VELOCITY WITHOUT SHROUD (m/s)</th>
<th>THROAT VELOCITY WITH SHROUD (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90</td>
<td>2.1</td>
<td>182.5</td>
<td>3.8</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>2.2</td>
<td>133</td>
<td>6.1</td>
<td>6.8</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>2.3</td>
<td>111</td>
<td>6.7</td>
<td>7.9</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>2.3</td>
<td>92</td>
<td>7.0</td>
<td>8</td>
</tr>
</tbody>
</table>

From this result the best position of shroud was fixed at **92cm** and further experiments were carried out at this point. We can see a difference in velocities with and without shroud at every distance which is very significant in power generation.

6.2 Boost In Air Flow

Under normal operating conditions, the air intake velocity of the fan was **2.1m/s**. On integrating with shroud the air flow was boosted to **2.3m/s**. This shows that this system can increase the mass flow rate of the draft fan in the cooling tower, due to the negative pressure gradient created.

6.3 Power Consumption Of Fan

The power consumption of the fan remained the same with the integration of the system. This shows that there is only positive effect on integrating this system with the draft fan.

6.4 Power Coefficient(Cp) vs Tip Speed Ratio(T.S.R) Curve

While loading the turbine we will get different values of current, voltage and speed. With this data we plot the Cp vs TSR curve as given below. The curve is having TSR in the X - axis and Cp in the y- axis.

Table 2: WITHOUT SHROUD (free stream 7 m/s)

<table>
<thead>
<tr>
<th>SL NO</th>
<th>SPEED (RPM)</th>
<th>VOLTAGE (V)</th>
<th>CURRENT (mA)</th>
<th>POWER (W)</th>
<th>CP (x10^-3)</th>
<th>TSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>169</td>
<td>14.9</td>
<td>.5</td>
<td>0.0075</td>
<td>5.52</td>
<td>0.68</td>
</tr>
<tr>
<td>2</td>
<td>153</td>
<td>13.1</td>
<td>.5</td>
<td>0.0066</td>
<td>4.86</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>148</td>
<td>12.5</td>
<td>.7</td>
<td>0.0088</td>
<td>6.48</td>
<td>0.596</td>
</tr>
<tr>
<td>4</td>
<td>141</td>
<td>11.5</td>
<td>1.9</td>
<td>0.022</td>
<td>0.162</td>
<td>0.48</td>
</tr>
<tr>
<td>5</td>
<td>81</td>
<td>6.4</td>
<td>5.7</td>
<td>0.036</td>
<td>0.265</td>
<td>0.378</td>
</tr>
<tr>
<td>6</td>
<td>13.1</td>
<td>1.2</td>
<td>10.7</td>
<td>.0128</td>
<td>9.42</td>
<td>.285</td>
</tr>
</tbody>
</table>
Table 3: WITH SHROUD (throat velocity 8 m/s)

<table>
<thead>
<tr>
<th>SL NO</th>
<th>SPEED (RPM)</th>
<th>VOLTAGE (V)</th>
<th>CURRENT (mA)</th>
<th>POWER (W)</th>
<th>CP (x10^-3)</th>
<th>TSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>345</td>
<td>29</td>
<td>1.3</td>
<td>0.038</td>
<td>1.87</td>
<td>0.68</td>
</tr>
<tr>
<td>2</td>
<td>328.6</td>
<td>28.4</td>
<td>1.7</td>
<td>0.048</td>
<td>2.36</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>304</td>
<td>26.5</td>
<td>2.1</td>
<td>0.056</td>
<td>2.76</td>
<td>0.596</td>
</tr>
<tr>
<td>4</td>
<td>245</td>
<td>24.6</td>
<td>3.08</td>
<td>0.076</td>
<td>3.75</td>
<td>0.48</td>
</tr>
<tr>
<td>5</td>
<td>192.6</td>
<td>22.5</td>
<td>3.84</td>
<td>0.0864</td>
<td>4.26</td>
<td>0.378</td>
</tr>
<tr>
<td>6</td>
<td>145.6</td>
<td>18.5</td>
<td>7.5</td>
<td>0.138</td>
<td>6.81</td>
<td>.285</td>
</tr>
</tbody>
</table>

Fig 6: Plot of CpVs TSR

Thus from the readings it can be seen that power coefficient with shroud is greater than that without shroud and shows a definite available air power increase due to velocity increase of air due to sucking effect of shroud. However tip speed ratio is less than one and the power generated is very low which is due to excessive drag force. The plot between the Cp and the TSR is plotted and we can see that the Cp decreases with increase in tip speed ratio in the case of shroud and in the case of without shroud the Cp is increasing sharply with increase in tip speed ratio and it drops suddenly after some point and then it again starts to increase which is contradictory to the standard results which is shown in FIG. 1.2. Hence, the design of wind blade has to be reviewed for further research. This disparity may be due to very low efficiency of generator and stall due to inaccurate fabrication of airfoil blade. Also there was eccentricity in rotation of the hub and generator leading to loss in power.

7. CONCLUSION

A very sincere attempt in the development and experimental demonstration of WIND LENS ENERGY RECOVERY SYSTEM (WERS) was made. The available wind power $P = \frac{1}{2} \rho AV^3$

$P = power \ in \ watts$

$\rho = The \ air \ density \ (1.2kg/m^3 \ @ \ sea \ level \ and \ 20^o \ C)$
A = The swept area of the turbine blades (m² square meters)
V = wind speed (meters per second)

increased from 13.58 W without shroud at a free stream velocity of 7 m/s to 20.27 W with shroud which shows a definite increase in velocity and hence available power by 66.99%. The curve between power coefficient (Cp) and tip speed ratio (TSR) is plotted for both with and without shroud. The maximum power coefficient obtained by experiment with shroud is $6.81 \times 10^{-3}$ and without shroud is $9.42 \times 10^{-4}$. Hence this system can be integrated into existing cooling towers which have the following advantages:

- Lower operating cost of cooling towers.
- Energy saved by this system can be fed to main power grid.
- This is a promising wind power alternative for areas with low wind velocity where natural windmills are not possible.
- Increased mass flow rate from cooling tower lowering the load on the fan.

The power output can be improved by providing real wind turbine blades and a proper electrical generator.

**8. FUTURE SCOPE**

- Existing wind lens design is for natural free stream velocity. This design can be suitably modified for the diverging wind stream coming from a draft fan so that this system can be more compact and can be kept closer to the draft fan for higher input velocities.
- Can be used in low wind speed areas for unnatural wind power generation as the wind lens enhances the speed of incoming air stream.
- To work on better design of airfoil profile to generate maximum lift.
- Testing this system on 2 blade and compare with 3 blade system to see which gives better power and more improved performance of cooling tower.

**REFERENCES**


