2011 International Conference on Environment and Industrial Innovation
IPCBEE vol.12 (2011) © (2011) IACSIT Press, Singapore

Exhaust Air and Wind Energy Recovery System for Clean Energy Generation

Chong Wen Tong [1] [+], Poh Sin Chew [1], Ahmad Fazlizan Abdullah [1],
Oon Cheen Sean [1] and Tiah Chai Ching [1]

[1] Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.

Abstract. An idea on harnessing clean energy from unnatural wind resources is presented in this paper. A vertical axis wind turbine (VAWT) in cross-wind orientation, with an enclosure is mounted above a cooling tower's exhaust fan to harness the wind energy for producing electricity. The performance of the VAWT and its effects on the cooling tower's air intake speed and current consumption of the power-driven fan were investigated. The enclosure design is optimized to create a venturi effect (to increase the wind speed) and guide the wind before the wind-stream interacts with the wind turbine blades. It also minimizes the risk of blade failure. Laboratory test conducted on a scaled model (5-bladed H-rotor with 0.3 meter rotor diameter) shows no measureable difference in the air intake speed (1.6~1.8 m/s) and current consumption of the power-driven fan (0.39 Ampere) when the turbine is spinning on top of the scaled model of the cooling tower. The electricity generated from this system can be utilized for commercial usage or fed into the electricity grid. This system is retrofit-able to the existing cooling towers and has very high market potential due to abundant cooling towers and other unnatural exhaust air resources globally.

Keywords: cooling tower, exhaust air, wind turbine, energy recovery, guide vane, clean energy

1. Introduction

Malaysia experiences low wind speed throughout the year (free-stream wind speed, V_∞ < 4 m/s for more than 90% of total wind hours). Thus, extracting wind energy by using conventional wind turbines in this condition would not be suitable. However, wind energy technology has developed rapidly over the decades; an innovative idea on harnessing wind energy from unnatural wind resources may be one of the answers to generate electricity.

Cooling towers are heat removal devices used to transfer waste heat to the atmosphere; large office buildings, hospitals and schools typically install one or more cooling towers for building ventilation system. Mechanical draft cooling towers are the most common cooling towers in Malaysia. This type of cooling tower relies on power-driven fans to draw or force the air through the tower. Wind speeds of up to 18 m/s is recorded at a distance of 0.3 meter above the outlet of the cooling tower, which is preferable for generating electricity.

A vertical axis wind turbine or Darrieus wind turbine with an enclosure is mounted above the fan to harness the wind energy and to produce electricity. The concern on safety is minimized by mounting the turbine with an enclosure; a mesh can also be used to fence the enclosure (to avoid bird strike problem and danger caused by blade failure). The enclosure design is also optimized to guide the wind and create a venturi effect to increase the wind speed before the wind-stream enters the wind turbine. The electricity generated from this system can be utilized to power the lighting system of the building or fed into the grid with authority imposed tariff. This system has very high market potential. It is retrofit-able to the existing

[+] Corresponding author. Tel.: +6012-7235038; Fax: +603-79675317.
E-mail address: chong_wentong@um.edu.my

cooling towers. In Malaysia alone, there are plenty of operating cooling towers and the market is growing rapidly; more and more cooling towers will be installed on new buildings.

2. Design Description

2.1. Technical Feasibility of Building Mounted/Integrated Wind Turbine

Over 50% of carbon dioxide emissions in the urban area are from the heating and cooling operations applied in buildings. Providing renewable energy directly to buildings would contribute to reducing their carbon dioxide emission. Wind turbine that incorporates within built environment (i.e. close to or on buildings) is defined as Building Mounted/Integrated Wind Turbine (BUWT). BUWT are turbines that are capable of working near to buildings and exploiting any possible augmentation on the local wind flow based on the knowledge of the architecture involved. They can be either independently supported or be a part of the building design [1]. Besides, the study conducted by Wright et al. proved that on-site generation has become more widespread for dwelling places, for example, photovoltaic panels, micro-CHP (Combined Heat and Power) and micro-wind [2].

Since the system is to be installed in a crowded urban area, specific design and guidelines are required for wind turbine in this environment. Special attention is required on safety issues regarding load experienced by the wind turbine, possibility of blade failure, vibration, etc. Public concerns such as noise and visual impact must not be neglected. Müller et al. have presented, technically and architecturally, the adoption of drag type VAWT for building integration based on a ducted wind turbine system [3]. Grant et al. have also reported that ducted wind turbine which is attached to the roof of a building has the significant potential for retrofitting onto the existing building with minimum visual impact [4].

2.2. Diffuser Design

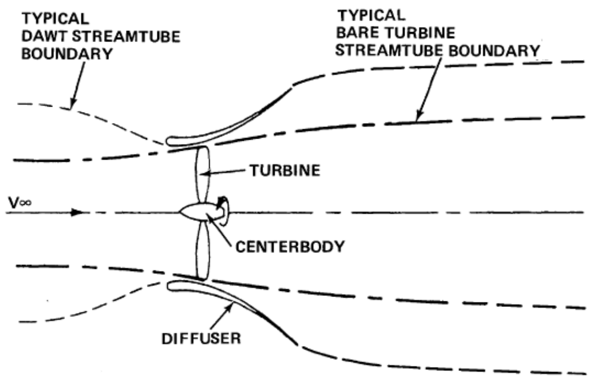

Fig. 1: Basic schematic drawing of the DAWT on the flow field boundaries [5].

Over decades, researchers have studied and reported different designs of ducted or funneled wind turbines, which increase the on-coming wind speed in order to increase the efficiency and performance of the wind turbine. Increasing the diffuser area as well as the negative back pressure at the diffuser exit was found profitable in the experiments. Claims were made that the performance augmentation with a factor of 4 or more were feasible, but those claims were not confirmed experimentally. With a simple momentum theory, developed along the lines of momentum theory for bare wind turbines, it was shown that power augmentation is proportional to the mass flow rate generated at the nozzle of the diffuser augmented wind turbine (DAWT). Such mass flow augmentation can be achieved through two basic principles: increase in the diffuser exit to inlet area ratio and/or by decreasing the negative back pressure at the exit [6]. The first principle to increase the exit to inlet area ratio is applied in the design as shown in Fig. 1, thus more energy can be harvested by utilizing this system.

Experimental and numerical investigations were conducted by Abe et al. for flow fields of a small wind turbine with a flanged diffuser (i.e. a diffuser-shrouded wind turbine). By processing the data obtained, characteristic values of the flow fields were estimated and compared with those for a bare wind turbine. The main conclusion derived from the study is that the diffuser-shrouded wind turbine provides much higher power output compared to the bare wind turbine. The power coefficient of the diffuser-shrouded wind turbine was about four times that of the bare wind turbines [7].

3. Working Principles and General Arrangement

A vertical axis wind turbine (VAWT) with an enclosure is mounted above the outlet of a cooling tower to harness the wind energy for electricity generation. The VAWT is positioned at a specific area and distance at the outlet of the exhaust air source to avoid negative impact on the performance of the exhaust air system whilst capturing more air. The design can be either in the horizontal or vertical direction. To capture the wind exhausted from the bottom (or top), the system can be installed horizontally with supporting structure at both ends of the power-transmission shaft with generator at one side and a bearing at the other side. If the exhaust air is blowing from side/wall, the system can be either horizontal or vertical. The generator can be mounted for vertical installation of the system.

The enclosure design is optimized to guide the wind and create a venturi effect (to increase the wind speed) before the wind-stream enters the wind turbine. The concern on safety is minimized by mounting the turbine inside an enclosure; a mesh can also be used to cover the enclosure (to avoid bird strike problem and danger caused by blade failure). Diffuser-plates form parts of the enclosure and are mounted at specific angles to draw more wind and accelerate the flow. The enclosure is also equipped with guide vanes to guide the wind to the correct angle of attack of the VAWT blades. The design is illustrated in Fig. 2.

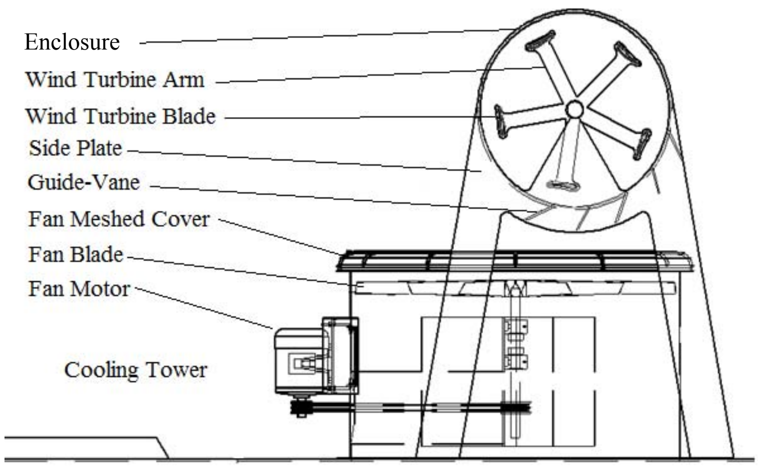

Fig. 2: Design arrangement of wind energy recovery system.

4. Experimental Set-up

The experiment was carried out on a small scale model using a 5-bladed H-rotor wind turbine with rotor diameter of 0.3 meter. The cooling tower is simulated by using a 0.4 meter diameter industrial fan enclosed in a 0.6 meter diameter cylinder duct. There is a gap at the bottom of the cooling tower with the distance of 0.1 meter from the floor (with air inlet area of 0.2714 m^2). The fan speed is set to the maximum (number 3 on selection buttons). The wind turbine is positioned above the simulated cooling tower's outlet and surrounded with an enclosure of 0.4 meter in diameter. The minimum distance between the wind turbine's blades rotating path and the outlet is 70 mm. The prototype and the experiment set-up are shown in Fig. 3.

The experiment was performed under three conditions; 1) cooling tower without wind turbine, 2) cooling tower with wind turbine, and 3) cooling tower with wind turbine surrounded by the enclosure. Several measurements were needed to investigate the difference between these three conditions. Current drawn by the fan motor was measured using a multimeter clamped on the life wire of the power cable. A cup anemometer was used to measure the air intake speed of the small scale model of the cooling tower. The rotational speed of the wind turbine was measured by a hand held laser tachometer.

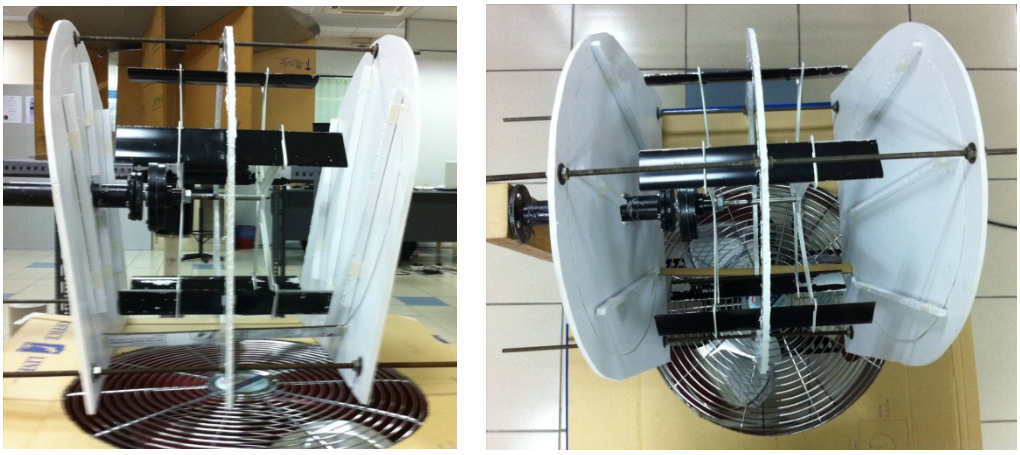

Fig. 3: Prototype and experimental set-up.

5. Result and Discussion

The proposed design is to recover part of the energy available in the exhaust air of the cooling tower without causing negative impact on the performance of the cooling tower. Based on the initial set-up of the small scale model of the cooling tower, the wind speed at the outlet of the cooling tower is 8.0 m/s. The other data obtained from all the set-up conditions are shown in Table 1.

Table 1: Laboratory testing on scaled model.

Laboratory testing model	Cooling tower without wind turbine	Cooling tower with wind turbine	Cooling tower with wind turbine and enclosure
Fan motor current consumption	0.39 Ampere	0.39 Ampere	0.39 Ampere
Intake air velocity	1.6 – 1.8 m/s	1.6 – 1.8 m/s	1.6 – 1.8 m/s
Wind turbine speed	-	115 rpm	150 rpm

For the simulated cooling tower with normal operating condition, the current drawn by the fan motor is 0.39 Ampere and the intake air velocity is in the range of 1.6 to 1.8 m/s. This condition was used as the baseline of the experiment. After the wind turbine was installed above the cooling tower's outlet, the wind turbine was spinning with 115 rpm (when it reached constant RPM). Whereas, the wind turbine surrounded with the enclosure recorded a rotational speed of 150 rpm. The results show that the design of enclosure effectively increases the speed of the wind turbine by 30.4%. There was no difference on the fan motor current consumption and intake air velocity for all three test conditions. On the other hand, if the exhaust outlet is covered with a circular flat plate, the current consumption of the cooling tower's fan will increase. The result shows that the installation of a wind turbine in these configurations will not affect the performance of the cooling tower and no additional load is added on the fan motor.

6. Conclusion

This paper presents an idea on harnessing clean energy from unnatural wind resources. Implementation of the shrouded VAWT on the outlet of cooling towers can recover a portion of the unused exhaust air for electricity generation. The enclosure design is optimized to create a venturi effect and guide the wind-stream to interact with the wind turbine blades. Both the outer plates are arrayed at a specific angle to act as a diffuser. Safety concerns due to blade failure and maintenance activities are tackled in the design of the system. From the initial testing done on the small scale model of a cooling tower (5-bladed H-rotor of 0.3 meter in diameter); when the wind turbine is spinning on top of the exhaust air outlet, there are no measureable differences in the air intake speed (1.6 – 1.8 m/s) and current consumption of the power-driven fan (0.39 Ampere). In addition, the enclosure significantly improves the wind turbine rotational speed from 115 rpm to 150 rpm. The electricity generated from this micro wind generation system can be utilized for commercial purposes or fed into the electricity grid. Assuming a 2 meters diameter cooling tower requiring 7.5 kW power for 16 hours operation, 131.4 GWh/year of power consumption will be utilized to operate 3000 similar units of cooling tower. This amount can be reduced by 13% with the proposed exhaust air and wind energy recovery system, which is equivalent to 17.1 GWh/year.

7. Acknowledgement

The authors would like to thank the University of Malaya for the assistance provided in the patent application of this design, and the research grant allocated to further develop this design under the project RG039-09AET. Special appreciation is also credited to the Malaysian Technology Expo (MTE 2011) for the affirmation of this project's potential (Gold Medal Award) to lead the world into a greener future. Last but not least, sincere gratitude is extended towards others who contributed to this project.

8. References

[1] A. G. Dutton, J. A. Halliday, and M. J. Branch. The Feasibility of Building Mounted/Integrated Wind Turbines (BUWTs): Achieving Their Potential for Carbon Emission Reductions, Final Report. Energy Research Unit, CCLRC, United Kingdom, 2005.

[2] A. Wright, and S. Firth. The Nature of Domestic Electricity-Loads and Effects of Time Averaging on Statistics and On-Site Generation Calculations. *Applied Energy*. 2007, **88**: 389-403.

[3] G. Müller, M. F. Jentsch, and E. Stoddart. Vertical Axis Resistance Type Wind Turbines for Use in Buildings. *Renewable Energy*. 2009, **34** (5): 1407-1412.

[4] A. Grant, C. Johnstone, and N. Kelly. Urban Wind Energy Conversion: The Potential of Ducted Turbines. *Renewable Energy*. 2008, **33** (6): 1157-1163.

[5] K. M. Foreman. Preliminary Design and Economic Investigations of Diffuser Augmented Wind Turbines (DAWT). Research Department Grumman Aerospace Corporation Bethpage, New York, 1981.

[6] G. J. W. V. Bussel. The Science of Making More Torque from Wind. *Journal of Physics: Conference Series*. 2007, **75**: 1-13.

[7] K. Abe, M. Nishida, A. Sakurai, Y. Ohya, H. Kihara, E. Wada, and K. Sato. Experimental and Numerical Investigations of Flow Fields behind a Small Wind Turbine with a Flanged Diffuser. *Journal of Wind Engineering and Industrial Aerodynamics*. 2005, **93**: 951–970.