Wind Energy Harvester Application: Cooling Tower

Interim Report

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Abstract

This project aims to collect information about the velocity of the exhaust air expelled by cooling towers as well as design a system capable of harnessing the energy of the wind. The idea is to take advantage of today's leading renewable energy solutions - the wind turbine - and adapt it for harvesting a potentially wasted form of energy from the cooling tower exhaust. With this project, a preliminary design as well as explorations on future design considerations are discussed.

Introduction

In a developed tropical country like Singapore, many industrial, residential and commercial buildings adopt the use of Heating, Ventilation and Air Conditioning (HVAC) systems as an integral part of everyday operations to provide cooling and humidity control.

One integral part of cooling systems is the use of cooling towers, which uses air to cool the warm water as a product of the cooling system [1]. For the purpose of this project, the type of cooling tower that is studied to provide wind energy is an induced draft cooling tower which utilises a fan to force air out from the top of the cooling tower. This constant airflow, from the surrounding air to the exhaust at the top, cools down warmer water from the cooling system for it to be returned as cooled water. [2]

The focus of this project is to design a suitable energy harvesting wind turbine for cooling towers. In general, wind turbines require a consistent and high quality wind source of reasonable velocities. Winds in Singapore in general are not favourable in this aspect where wind speeds on average are about 2m/s. However, exhaust systems like cooling towers provide such consistency and are readily available in many buildings in Singapore.

In our project, the idea of the Horizontal Axis Wind Turbine is the prime consideration for the design of our wind energy harvester as it takes advantage of the unidirectional nature of the air at a point compared to the other wind turbine design in the Vertical Axis Wind Turbine.

The following section discusses the wind velocity of the cooling tower this project aims to harvest.

Feasibility

In order to determine the feasibility of the project, a [velocity height map] is mapped using measurements on-site of a working cooling tower outlet located at NUS Engineering Block E2. The cooling tower tested was situated at rooftop which is a common location for a HVAC cooling tower, where background winds could significantly affect our wind speed readings. As such, readings were done when the perceived background wind is at its lowest.

Figure 1: Cooling tower fan that was tested

From initial on-site analysis of the air outflow, the maximum height from the grid of the outlet with a significant wind speed reading was 30 cm. At this height, the perceived air flow from the cooling tower fan was too weak, and wind speed readings were due to background wind.

The readings were done on two height levels - at grid level, which is the closest to the cooling tower fan, and 15 cm above the grid where wind speeds are perceived to be strongest and most consistent. Readings were also taken radially, from the centre of the cooling tower fan and moving outwards to the rim. Wind speeds of two directions were also recorded, in the Z and R directions; namely wind upwards and wind outwards.

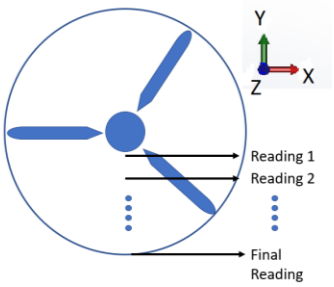


Figure 2: Positions of readings done on the cooling tower outlet

These results will be used to design the wind harvester. Positions with maximum wind speeds and positions with the minimum required wind speed, to power the turbine, will be taken into consideration.

Results

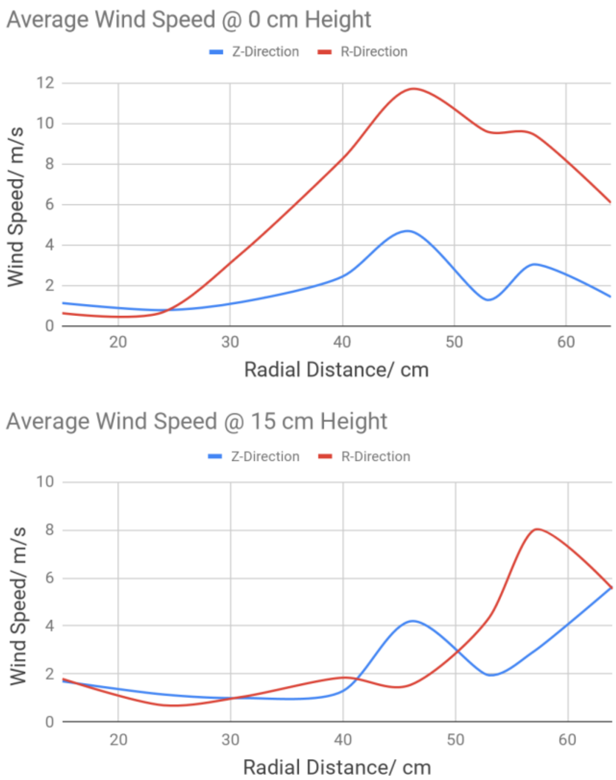
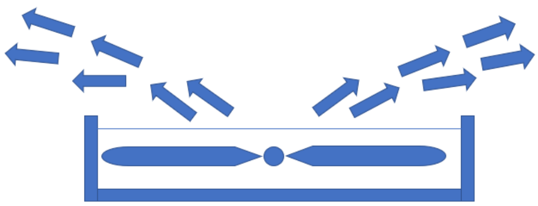


Figure 3: Average Wind Speeds at 2 height position in R and Z directions

Analysis of the results revealed that for our target cooling tower, the wind velocity profile of the outlet shows a radially directed wind flow, as evident from the more prominent R-direction wind speeds than in the Z-direction.



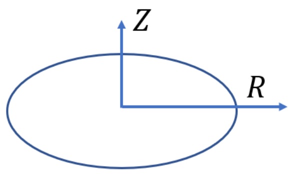


Figure 4: Visual Representation of Air pathway for cooling tower outlet.

Results showed that at an optimal position (48cm, r direction, 50Hz) above the cooling tower, wind speeds can be consistently at approximately 11.7m/s , which is much higher than 5m/s, the minimal requirement of a commercial wind farm (Mathew, 2006).

From these results, it is shown that the cooling tower outlet is capable of producing air velocities required for a small-scale wind turbine to be installed.

As such, the most optimal harvesting direction is along the direction of the output wind (R-direction) at the side of the cooling tower.

Wind Energy Harvester Design Consideration

Generator - Working Principle

For our project, the principle of electromagnetic induction is explored by which kinetic energy from motion of the magnets is converted to electrical energy through the induction of electromotive force or a potential difference across the inductor coil.

$$\varepsilon = -\frac{N d\phi}{dt} \qquad (1)$$

$$\phi = \int_S \boldsymbol{B}.d\boldsymbol{A} \qquad (2)$$

ε = electromotive force (emf)
ϕ = magnetic flux
N = number of turns of coil
B = magnetic field

In order to maximise the voltage output, the induced emf needs to be maximised as well, as seen from eqn. (2). This can be done by (i) increasing the rate of change of magnetic flux, dϕ and (ii) increasing the number of coils, N.

For our generator design, the magnet used will be neodymium ring magnets which is a rare earth element magnet with high magnetic field strength which in turn increases $\phi$from eq. 2.

The nature of the emf in our case will be an alternating current due to how the magnets induce emf by continuously entering and leaving the vicinity of the coils. As such, this alternating current is rectified and smoothed, as discussed in the later section of this report.

Generator - Design

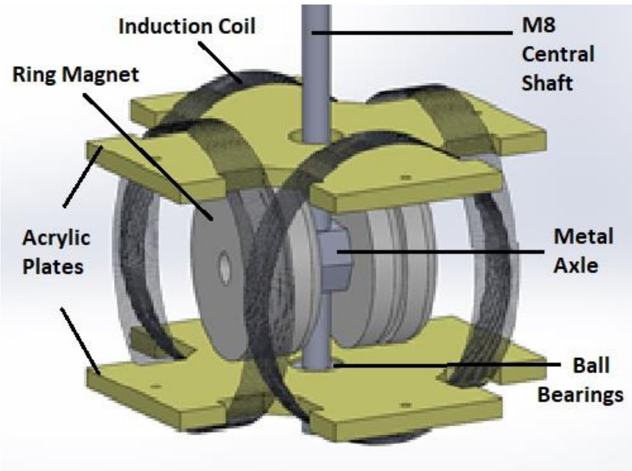


Figure 5: Solidworks representation of the generator

The generator will consist of 4 x 4.8 mm diameter ring magnets attached to an axle which is fixed on a central shaft. An m8 threaded central shaft is directly connected to the fan blades which turns with the blades. The central shaft is also attached to 2 designed acrylic plates with individual ball bearings to ensure the stability of the shaft rotation. It features 4 induction coils placed on the side of the magnets to be rotated as seen in figure 5.

Generator - Circuit

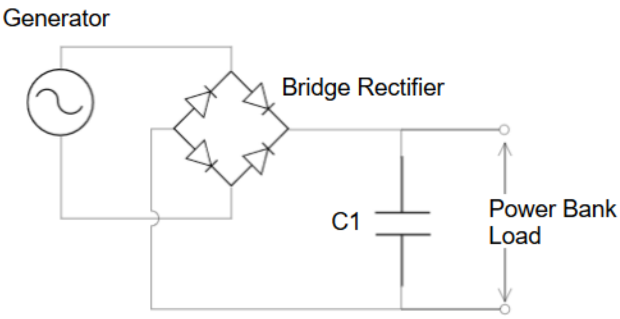


Figure 6: Full-wave rectifier

Each of the induction coils of the generator will be connected to a rectifier circuit and smoothing capacitor as seen in figure 6. The rectifier circuit, assuming each diode has a voltage drop of 0.6V, will cause a 1.2V voltage drop. The type of energy storage bank used will be determined by the ability of the generator system to achieve constant 5V output for a power bank or 1.5V for a rechargeable battery. In order to charge a 5V power bank or a 1.5V battery, assuming a ripple voltage of 20%, our voltage output would be 6.25V or 1.9V respectively.

For a full wave rectifier:

$$V_{ripple} = \frac{I_{load}}{2fC}$$

For our generator, the frequency of the system will be highly dependent on the frequency of the fan blade rotation. As such, to achieve a ripple voltage of 1.25V for a power bank, or 0.4V for a rechargeable battery, the capacitor value, C will be varied as such based of the blade rotation frequency under test conditions.

Wind Turbine

There are 2 main types of industrial wind harvesters which are the Vertical Axis Wind Turbine (VAWT) and the Horizontal Axis Wind Turbine (HAWT), as shown in Figure 7.

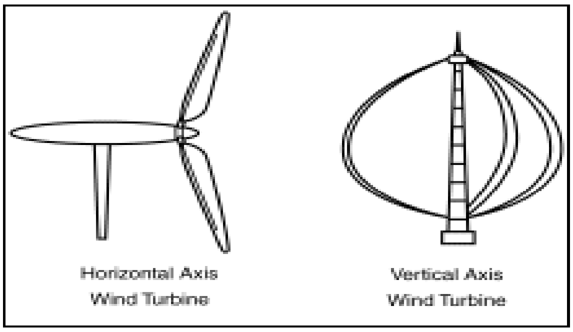


Figure 7: HAWT vs VAWT [4]

Our design is heavily based on the available types of wind turbines that are available today. As seen from the air velocity profile from the cooling tower fan, the design chosen would have to take advantage of the radially unidirectional output of the air from the cooling tower (Figure 8). The HAWT will harness more energy than its counterpart - the VAWT for this case. As such, our initial consideration for the type of wind turbine will be the HAWT.

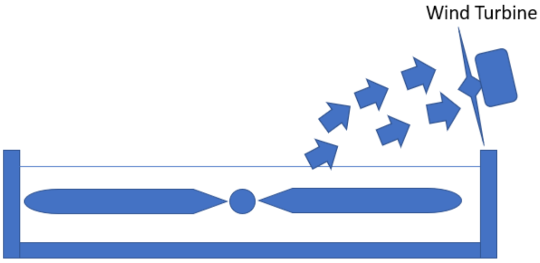


Figure 8: Placement position of the wind energy harvester

Conclusion

In the coming weeks, power generation of the wind turbine will be improved by optimising turbine blade shape for cooling tower wind speeds, number of coils in the generator as well as strength of magnet used.

The first prototype of the wind turbine will be made with the following specifications:

1. A three-blade turbine with a curvature of 30 degrees and blade length of 15cm.
2. 250 coils at four edges of the acrylic plates for the generator
3. Cylindrical neodymium magnets will be used for electromagnetic induction as they are the strongest available magnets.

Our team is optimistic that this project will be very beneficial for harvesting waste exhaust winds from all cooling tower systems, to reduce energy consumption and increase sustainability.

References

[1] CTI. Cooling Tower Detail. [Online]. Available: https://www.cti.org/whatis/coolingtowerdetail.shtml

[2] BrighthubEngineering. [Online]. Available: https://www.brighthubengineering.com/hvac/100882-hvacr-cooling-towers-and-their-types/

[3] Mathew, S. (2006). *Wind Energy Fundamentals, Resource Analysis and Economics*. Verlag, Berlin: Springer.

[4] R. Beckers. (2006). The Truth about small wind turbines. [Online]. Available: https://www.solacity.com/small-wind-turbine-truth

Appendix

	50 Hz Wind Speed Velocity, V / (m/s)											
R/cm	Min 0Z	Max 0Z	Avg 0Z	Min 0R	Max 0R	Avg 0R	Min 15Z	Max 15Z	Avg 15Z	Min 15R	Max 15R	Avg 15R
15	0.6	1.7	1.15	0.5	0.8	0.65	1.1	2.3	1.7	1.5	2.1	1.8
24	0.5	1.1	0.8	0.4	1	0.7	0.5	1.8	1.15	0.4	1	0.7
31	1	1.4	1.2	3	4.2	3.6	0.6	1.4	1	0.6	1.5	1.05
40	2	2.9	2.45	7.4	9.1	8.25	0.7	1.9	1.3	1.2	2.5	1.85
46	1.8	7.6	4.7	10.6	12.8	11.7	1.7	6.7	4.2	1.1	2	1.55
53	0.8	1.8	1.3	8.2	11	9.6	0.8	3.1	1.95	3	5.7	4.35
57	2	4.1	3.05	8	11	9.5	2	3.9	2.95	6.2	9.8	8
64	0.7	2.2	1.45	5.4	6.8	6.1	4.2	7.1	5.65	4.1	7	5.55