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Design of an exhaust air energy recovery wind turbine generator for energy conservation in commercial buildings☆

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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. Two vertical axis wind turbines (VAWTs) in cross-wind orientation which are integrated with an enclosure are installed above a cooling tower to harness the discharged wind for electricity generation. It is mounted at a specific distance and position above the cooling tower outlet. The enclosure (consisting of several guide-vanes and diffuser-plates) acts as a wind power-augmentation device to improve the performance of the VAWTs. The guide-vanes are placed in between the discharged air outlet and the wind turbine. They are designed to guide the on-coming wind stream to an optimum flow angle before it interacts with the rotor blades. The diffuser-plates are built extended from the outlet duct of the exhaust air system. They are tilted at an optimum angle to draw more wind and accelerate the discharged air flow. A particular concern related to public safety which may be due to blade failure is minimized since the VAWTs are contained inside the enclosure. The performance of the VAWTs and its effects on the cooling tower's air intake speed and current consumption of the power-driven fan were investigated. A laboratory test was conducted to evaluate the effectiveness of the energy recovery wind turbine (5-bladed H-rotor with 0.3 m diameter) generator on a cooling tower model. The results showed a reduction in the power consumption of the fan motor for cooling tower with energy recovery turbine compared to the normal cooling tower while the intake air speed increased. Meanwhile, the VAWT's performance was improved by a 7% increase in rotational speed and 41% reduction in response time (time needed for the turbine to reach maximum rotational speed) with the integration of the enclosure. This system can be used as a supplementary power for building lighting or fed into electricity grid for energy demand in urban building. The energy output is predictable and consistent, allowing simpler design of the downstream system. The fact that there is an abundance of cooling tower applications and unnatural exhaust air resources globally causes this to have great market potential.

1. Introduction

Dependency on fossil based energy resources leads to the energy crisis due to depletion of these resources. Increase of population and economic growth contribute to higher demands of energy that only worsens the situation. Therefore, one of the most important concerns globally is the need of energy security. Energy generation from renewable resources such as wind, solar, tidal and biomass is one of the options to reduce the dependency on fossil resources. The idea of on-site renewable energy generation is another great approach where the energy is extracted from renewable sources close to the populated area where the energy is required. However, renewable energy generations are highly dependent on geographical conditions.

Urban areas are the places where energy is needed most. In Malaysia, at an urban area, the wind speed is less than 4 m/s for more than 90% of the total hours in a year [1]. This value is not conducive for on-site energy generation from wind. However, in this paper, an innovative idea to generate clean energy from alternative wind resources in urban areas is presented. The alternative source of wind is from the exhaust air systems.

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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 [2]. 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 project is to develop an energy recovery system by installing vertical axis wind turbines (VAWTs) at the outlet of the cooling tower to generate electricity from the wasted discharged air. The VAWTs are surrounded by enclosures to improve the performance as well as the air flow of the cooling tower.

However, it is essential to ensure that this additional feature does not provide a negative impact to the cooling tower. An optimized cooling tower has the optimum ratio of the mass rate of flow of circulating water to the mass rate of flow of dry air [3]. For the case of this energy recovery turbine generator, only parameters related to the dry air, i.e. mass flow rate, fan rotational speed, intake speed, outlet speed and fan motor power consumption might be affected. This paper reports the results for the experiments that have been conducted in developing the energy recovery turbine generator.

2. Literature review

2.1. Factors that affect cooling tower performance and performance testing on an induced-draft cooling tower

Direct-contact induced-draft cooling towers are the most common cooling tower in Malaysia. Fig. 1 shows an example of a cross-flow direct-contact induced-draft cooling tower. This type of cooling tower relies on power-driven fans to draw or force the air through the tower. The air enters the cooling tower through the louver at the sides of the tower. Then, it is forced to flow upwards until the exit on top of the tower and at the same time, it is in contact with the water that is flowing downwards. The cross-flow heat transfer from water to the air happens when they are in contact. The heat in the air is then released to the atmosphere at high speed through the outlet channel. Wind speeds up to 18 m/s are recorded at a distance 0.3 m above the outlet the of cooling tower, which is preferable to generate electricity [4].

There are a lot of factors which affect the cooling tower air flow performance, i.e. interference and recirculation. Interference happens when a portion of the wind from the outlet of a cooling tower contaminates with the air intake of the other cooling tower [6]. Therefore, a proper design especially on the discharge height and the distance between the cooling towers is necessary to minimize the interference. On the other hand, recirculation or sometimes called re-entrainment is another undesirable situation that affects the performance of a cooling tower. The basic principle of the cooling tower is to take the fresh ambient air into the compartment for the air to absorb and carry the heat out of the cooling tower through the outlet. If the discharged air is recirculated by contamination with the intake air, the performance of the cooling tower will be affected. The potential for recirculation is primarily related to ambient wind force and direction. It tends to increase as the ambient wind velocity increases [6]. When the strong wind blows towards the cooling tower, the discharge air is forced to change direction and causes it to contaminate with the intake air.

There are many factors that affect the cooling tower performance such as water distribution, air distribution, water inlet and outlet temperature, etc. However, in case of troubleshooting, fan flow characteristic is one of the first items to be investigated. In order to evaluate the performance of the fan, the parameters to be measured are the air flow rate, power input to motor and fan speed [7].

2.2. The use of diffuser to improve wind turbine performance

Besides focusing on improving the performance of the wind turbine by the aerodynamic study of the turbine blades, increasing the on-coming wind speed before it interacts with the wind turbine also provides a significant result in power generation increment. The power in the wind is proportional to the cube of the wind speed, which means that even a small increment in wind speed gives a large increase in energy generation. Therefore, many researchers had studied and reported different designs of ducted or diffuser augmented wind turbines, which increase the on-coming wind speed hence increasing the efficiency and performance of turbines. Mass flow augmentation can be achieved through two basic principles, i.e. increase in the diffuser exit ratio or decrease

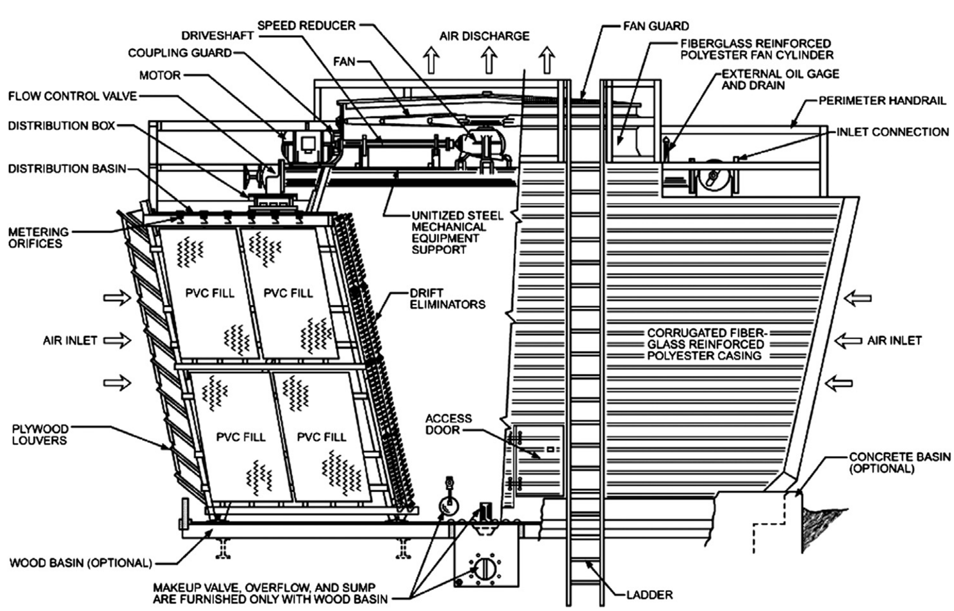

Fig. 1. Cross-flow direct-contact induced-draft cooling tower [5].

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