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The design, simulation and testing of an urban vertical axis wind turbine with the omni-direction-guide-vane ☆

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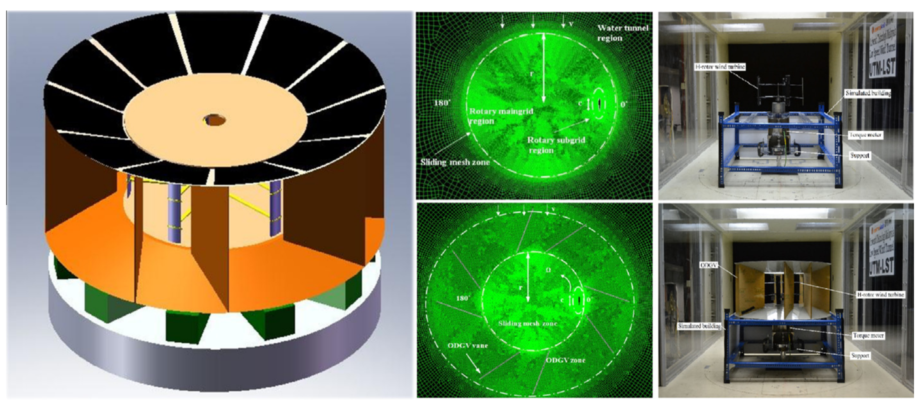
HIGHLIGHTS

- ▶ A system for on-site wind–solar hybrid power generation and rain water collection.
- ▶ The omni-direction-guide-vane (ODGV) overcomes the weak wind and turbulence conditions in urban areas.
- ▶ The ODGV improves the wind turbine performance by speeding-up and guiding the wind.
- ▶ The ODGV is designed to blend into the building architecture with safety enhancement.
- ▶ The wind tunnel test and CFD simulation results are presented.

GRAPHICAL ABSTRACT

Solar energy, renewable energy, urban wind energy, environment, augmented wind turbine.



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ABSTRACT

A novel omni-direction-guide-vane (ODGV) that surrounds a vertical axis wind turbine (VAWT) is designed to improve the wind turbine performance. Wind tunnel testing was performed to evaluate the performance of a 5-bladed (Wortmann FX63-137 airfoil) H-rotor wind turbine, with and without the integration of the ODGV. The test was conducted using a scaled model turbine which was constructed to simulate the VAWT enclosed by the ODGV placed on a building. The VAWT shows an improvement on its self-starting behavior where the cut-in speed was reduced with the integration of the ODGV. Since the VAWT is able to self-start at a lower wind speed, the working hour of the wind turbine would increase. At a wind speed of 6 m/s and under free-running condition (only rotor inertia and bearing friction were applied), the ODGV helps to increase the rotor rotational speed by 182%. With extra load application at the same wind speed (6 m/s), the wind turbine power output was increased by 3.48 times at its peak torque with the aid of the ODGV. The working concept of the ODGV is to minimize the negative torque zone of a lift-type VAWT and to reduce turbulence and rotational speed fluctuation. It was verified by re-simulating the torque coefficient data of a single bladed (NACA 0015 airfoil) VAWT published by the Sandia National Laboratories. From the simulation results, with the presence of the ODGV, it was shown that the torque output of the NACA 0015 airfoil, single bladed VAWT has been increased by 58% and 39% at TSR = 2.5 and TSR = 5.1 respectively. The negative torque zone has been minimized thus the positive torque that provides higher power can be obtained. As a conclusion, the ODGV integrated wind power

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generation system improves the power output of a VAWT and it has great potential to be sited in urban areas for on-site and grid-connected power generation.

Nomenclature

Abbreviations

ODGV	omni-direction-guide-vane
VAWT	vertical axis wind turbine
PAGV	power-augmentation-guide-vane
TSR	tip speed ratio
CFD	computational fluid dynamics
PV	photovoltaic
O&M	operation and maintenance

Symbols

c	airfoil chord length (m)
r	rotor radius (m)
v	wind speed (m/s)
Ω	rotational speed (rad/s)
$r{\cdot}\Omega$	rotor tip speed (m/s)
C_τ	torque coefficient

1. Introduction

Economic growth and energy demand are intertwined. Therefore, one of the most important concerns of the government and in the world is the need for energy security. Developed countries are known as the major users of energy globally, however, increasing demands will occur in developing countries, where populations, economic activities and improvements in quality of life are growing most rapidly. Currently, the world relies on coal, crude oil and natural gas for energy generation. However, the energy crisis together with climate change and depletion of oil have become major concerns to all countries.

Therefore, alternative energy resources such as wind energy and solar energy have attracted interest from both public and private sectors to invest in energy generation from these sources extensively. There is an obligation for us to adopt these available sustainable green technologies into the dwelling places. The government of the United Kingdom enforces The Climate Change Act 2008 where one of the objectives is to reduce their carbon dioxide emissions by at least 80% by 2050 against a 1990 baseline [1]. China, as the largest carbon emissions country in the world has begun to implement "energy-saving and emission reduction policy" and put forward a binding target of decreasing energy consumption per unit GDP by about 20% and reducing the total emission of main pollutants by 10% during the country's 11th 5-year plan [2]. In Malaysia, the government introduces the feed-in-tariff mechanism to encourage the utilization of renewable energy sources in electricity generation [3].

On-site energy generation is becoming more widespread for dwelling places, for example, photovoltaic panels, micro-CHP (Combined Heat and Power) and micro-wind [4]. The concept of on-site renewable energy generation is to extract energy from renewable sources close to the populated area where the energy is required [5]. Dayan [6] has suggested that mounting turbines on the top of high-rise buildings may provide the perfect opportunity for urban on-site generation from wind power. However, in order to retrofit the wind turbine system, the issues of safety, noise, vibration and visual impact should not be underestimated [7].

This paper presents an innovative device called the omni-direction-guide-vane (ODGV) for integration with a vertical axis wind turbine (VAWT) for on-site energy generation. The ODGV is a revolution of the power-augmentation-guide-vane (PAGV) design as fully discussed in the references [5,7,8]. It is designed to improve the performance of a wind turbine in terms of power output, rotational speed and self-starting behavior. Wind tunnel tests and computational fluid dynamics (CFD) simulation were performed to measure the effectiveness of the device to improve the performance of the VAWT.

2. Building integrated wind turbine

Building integrated wind turbines are gaining more and more attention for urban on-site clean energy generation. It is desirable to locate wind turbines in regions of high wind speed and low turbulence for optimum performance; however, urban areas often experience the opposite conditions [9]. Therefore, wind turbine systems need to be designed and optimized for operation in urban areas.

Today, many green building projects are going to mature where some of them are still in the conceptual design stage, some are in the construction stage, and some are already inaugurated. Bahrain World Trade Centre is the world's first large-scale integration of wind turbines with a building. This 240 m high building harmoniously integrates building augmented design with three horizontal axis wind turbines of 29 m diameter [10]. Another iconic building is the Strata Tower of London that was built to incorporate wind turbines within its structure. The turbines are anticipated to produce 8% of the electricity needs of the building [11]. Stankovic et al. [12] has proposed two conceptual designs of building integrated wind turbine. The first design is the omni-direction turbines that are suspended in ducted holes spanning multiple storeys, which connect four 360 m tall towers. Another design is the 200 m twin tower inspired by the aerodynamically efficient 'boomerang' footprint with the symmetrical shape of the two towers creating an aerodynamic fit around the three integrated HAWTs. However, the construction of these buildings involves a very high capital that makes the developers reluctant to build them.

With further consideration of building and architectural integration, many researchers introduced and tested different types of wind turbine. A concept and early development of the wind turbine called Crossflex, utilized an existing Darrieus turbine concept, but it was applied in a novel form for building integration [13]. The ducted wind turbines which are attached to the building roof have a significant potential for retrofitting into a building with small concern of visual impact [14]. In order to facilitate current building design, Müller et al. [15] has proposed and architecturally demonstrated a wind energy converter with a cylindrical form (according to the building's profile).