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Performance investigation of a power augmented vertical axis wind turbine for urban high-rise application☆

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ABSTRACT

A shrouded wind turbine system has a number of potential advantages over the conventional wind turbine. A novel power-augmentation-guide-vane (PAGV) that surrounds a Sistan wind turbine was designed to improve the wind rotor performance by increasing the on-coming wind speed and guiding it to an optimum flow angle before it interacts with the rotor blades. The integration of the PAGV into the 3-in-1 wind, solar and rain water harvester on high-rise buildings has been illustrated. A particular concern related to public safety is minimized when the wind turbine is contained inside the PAGV and noise pollution can be reduced due to the enclosure. Besides, the design of the PAGV that blends into the building architecture can be aesthetic as well. Moreover, a mesh can be mounted around the PAGV to prevent the bird-strike problem. From the wind tunnel testing measurements where the wind turbine is under free-running condition (only rotor inertia and bearing friction were applied), the wind rotor rotational speed (with the PAGV) was increased by 75.16%. Meanwhile, a computational fluid dynamics (CFD) simulation shows that the rotor torque was increased by 2.88 times with the introduction of the PAGV. Through a semi-empirical method, the power output increment of the rotor with the PAGV was 5.8 times at the wind speed of 3 m/s. Also, the flow vector visualization (CFD) shows that a larger area of upstream flow was induced through the rotor with the PAGV.

1. Introduction

Renewable energy such as wind energy and solar energy is receiving great attention due to the price fluctuation of fossil fuels in the international market as well as adverse environmental problems from the process of power generation from fossil fuels. There is an obligation for us to adopt these available sustainable green technologies into our dwelling places. In Europe, the member states have taken effort to increase the energy efficiency by 20% and reduce their global warming emissions by 20% (based on 1990 levels) by 2020 [1]. Wind energy has long been recognized as a potential source of renewable energy. In the past few decades, wind-power technology has achieved an outstanding maturity status, while an astonishing improvement has taken place in the battery construction and electronic equipment sectors [2]. Meanwhile, wind turbine capacity has also increased from the classical 250 W to 5 MW. Wind farms as big as 500 MW exist in Spain and USA [3]. Wind also has a capacity credit; during the peak energy demand in countries with four seasons especially in winter, the wind blows harder when it is cold and thus more energy can be captured from the wind [4].

In a study conducted by Knight [5], it was reported that there is a great potential to site wind energy generators in urban areas and the research works undertaken were led by the European Union. For on-site generation, building integrated wind turbines and solar energy systems serve as attractive opportunities. High-rise buildings would be a good choice for on-site wind turbine integration. However, urban areas generally have weak and turbulent wind conditions due to the presence of high-rise buildings [5]. Thus, wind energy generation systems for urban regions need to overcome these disadvantages. Vertical axis wind turbine (VAWT) possesses great advantages and is particularly suitable to be built in a turbulent environment [6]. Moreover, drag-type VAWT could be considered for on-site wind energy generation due to its low cut-in

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Nomenclature

CFD	computational fluid dynamics
HAWT	horizontal axis wind turbine
PAGV	power-augmentation-guide-vane
SIMPLE	semi-implicit method for pressure linked equations
SST	shear–stress transport
VAWT	vertical axis wind turbine
A_R	swept area of rotor
$C_{P(avg)}$	average power coefficient
c_d	drag coefficient of air
F_D	drag force
P_S	power extracted
$P_{S(avg)}$	average power extraction
S	wind-blown surface
V_0	air velocity when hitting the wind-blown surface
V_S	velocity at which the wind-blown surface moves
V_∞	free-stream wind speed
ρ	density of air
τ_{avg}	average torque
Ω	angular speed

wind speed, good starting behavior and simplicity in fabrication. A research at Heriot-Watt University shows that an alternative approach is to focus on the development of turbines that would allow for electricity production at lower cut-in speeds, i.e. more suitable for urban terrain [7].

The advantages are that the VAWT does not have to be mounted high in the sky to get a good enough wind source to generate power. Generally, the VAWT can start to generate power at a lower wind speed than the horizontal axis wind turbine (HAWT), therefore it can be mounted lower than other wind turbine generally would be mounted [8]. This defining feature makes it more residential friendly because it can be mounted on the top of a building. Besides, the VAWT is able to catch the wind from any direction. Müller et al. [9] have presented, technically and architecturally, the adaptation of drag-type VAWT for building integration based on a ducted wind turbine system. Grant et al. have also reported that ducted wind turbine which was attached to the roof of a building has a significant potential for retrofitting onto the existing building with minimum visual impact [10].

2. Building integrated wind–solar hybrid energy generation system and rain water collector

Nowadays, there are combinations of many alternative resources such as solar–diesel, wind–diesel, wind–solar–diesel and solar–diesel–hydro–fuel cell to form hybrid energy generation systems [11,12]. But due to the increasing public awareness on environmental protection, a lot of research has been concentrating on clean and sustainable energy such as photovoltaic (PV) and wind energy systems [13,14]. In this paper, a novel shrouded wind turbine system that integrates several green and renewable energy harvesting technologies (wind–solar hybrid energy generation system and rain water collector) is proposed for use on high-rise buildings as illustrated in Fig. 1. An innovative device called the power-augmentation-guide-vane (PAGV) is introduced [15]. The PAGV that surrounds a drag-type VAWT was designed to improve the wind rotor performance by increasing the on-coming wind speed and guiding it to an optimum flow angle (to avoid negative torque acting opposite to the rotor rotation [16]) before it interacts with the rotor blades. The system is designed to overcome the weak and turbulent wind conditions in urban areas, which are unsuitable for conventional wind turbine operation. The system is also designed to provide an optimum surface area for solar panel installation on top of the harvester (outer surface of the PAGV upper wall) to generate energy from sunlight. In addition, rain water can be collected through the flow paths formed by the multi-sector arrangement of the inclined solar panels. The rain water flows toward the center of the system and the collected rain water can be stored in a storage tank for various purposes including micro-hydro power generation. The system is designed to complement the building architecture with minimal visual impact so as to overcome the issue concerning public acceptance [17].

A techno-economic analysis has been carried out on this innovative hybrid renewable energy system with the PAGV [18]. From

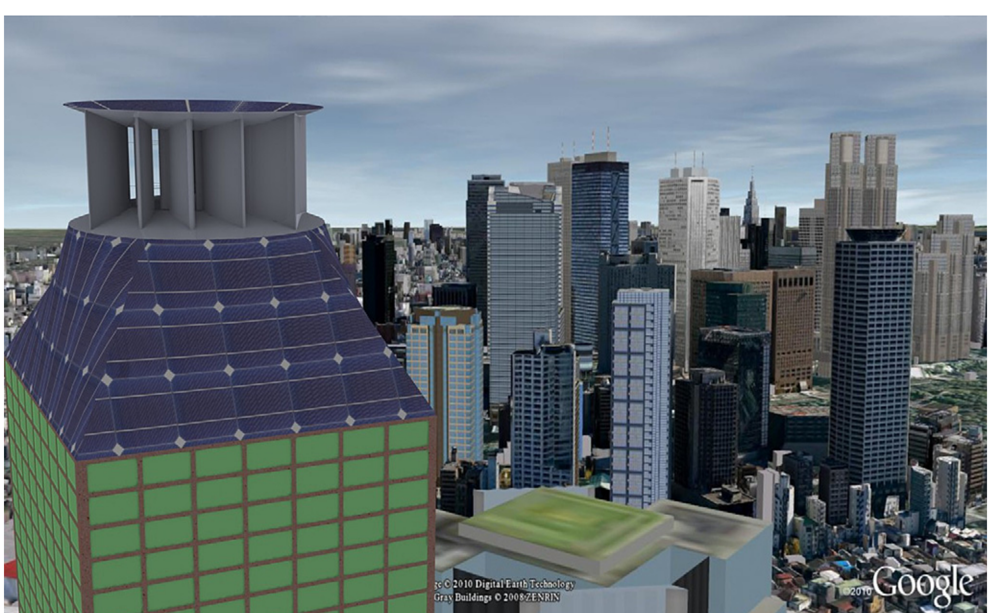

Fig. 1. Illustrative view of a high-rise building with the hybrid renewable energy system integrated on it. The background is a modified view of Tokyo City by Google [18].