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Cross-Flow Small Scale Wind Turbines: An Overview of Technology Development and Applications

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Abstract
Vertical axis turbines, mainly as a category of small-scale turbines, attract interest and develop further every day. The Cross-Flow wind turbine (CFWT) is one of these, which is quite suitable for urban and home applications, though its low maximum power coefficient is still a challenge that feasible methods must address. This article reviews studies in the field of design and improvement of CFWT by changing the CFWT geometric characteristics or designing the augmentation devices. After introducing the CFWT, the methods for directing wind flow and their effects on the turbine performance are described. These methods are divided into seven categories: guide nozzle, casing, guide vane, deflector, cowling, Omni-Directional Guide Vane (ODGV), and Zephyr. According to this study, ODGV development accounted for a significant amount of the research. CFWT was also investigated in Iran for the cities of Ardabil, Babolsar, and Zahedan, using three different types of systems (direct sale, on-grid, and on-grid with batteries). This analysis reveals that direct sales are the optimum strategy for operating a CFWT in Iran, and a payback period time of fewer than 10 years is possible just by lowering the CAPEX of the setup by 10%–29%.

Keywords: Renewable energy, Small scale wind turbine, Cross-flow turbine, Wind energy, Power coefficient.

1. Introduction

Although the damage caused by fossil fuels to the environment had been known for centuries, humans did not seek to use clean energy until the 1970s (1973 oil crisis and 1978 energy crisis). Nuclear energy has been seen as a solution to cheap and abundant fuel. However, its development and expansion have gradually declined over the years due to its rising costs, safety, manufacture, and use as weapons of mass destruction [1].

Sustainable energy sources are resources that do not diminish over time, do not pollute the environment, do not pose health hazards, and do not cause social injustice [1]. Solar, wind, geothermal, hydrogen (fuel cells), biomass, hydroelectric, and heat generators are the only sources of sustainable and renewable energy that have these properties. Wind energy has become one of the world's most popular sustainable energy sources in the last decade. Wind turbine power plants and small-scale household wind turbines can both harvest this energy. Due to the growing global need for electricity, the development of wind turbines has accelerated. Nonetheless, the industry of vertical-axis wind turbines is a growing industry that is reforming and developing technologies. In the future, it may be a competitor to other renewable resources.

According to the Wind Atlas of Iran, the available wind energy is estimated to be about 40,000 MW. Nevertheless, only 900 MW of capacity has been built in the renewable power sector. Wind power plants account for 310 MW, solar power plants account for 390 MW, and the remainder is made up of small hydropower plants, biomass, and expansion turbines [2]. Some cities and villages, especially in the inaccessible areas of Iran, are in a perfect situation in terms of wind energy. The lack of access to sustainable electricity in these areas and the increasing demand in the household sector provide an excellent incentive to use small-scale wind turbines. Furthermore, in some areas where wind energy capacity is much higher than solar, one sensible option for generating clean energy is to use a wind turbine.

2. Material and Method

2.1. Review of Cross-Flow wind turbine

This study aims to introduce the Cross-Flow wind turbine, its advantages, disadvantages, and applications. Fig. 1 shows a Cross-Flow rotor with other structures. Because the Cross-Flow wind turbines have a small $C_{P,max}$ (approximately 0.12, depending on the rotor design and Reynolds number), this peak value should be increased. Recent experiments and simulations on the design and optimization of cross-flow wind turbines are reviewed. They all attempted to improve C_P and C_T by changing the rotor's geometric characteristics or providing methods to direct the wind flow into the rotor.

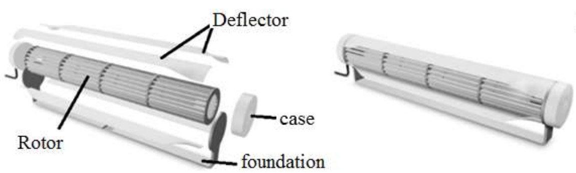

Figure 1 The structure of a Cross-Flow wind turbine [3]

2.2. usage of Cross-Flow turbines in Iran

To investigate the feasibility of using and analyzing Cross-Flow wind turbines in Iran, three cities with various climates were chosen: Babolsar (moderate), Ardabil (cold), and Zahedan (tropical). Meteorological data such as air temperature, wind speed, and direction are collected hourly for a year. The turbine power generation is calculated from Equation (1), where the C_P is obtained from the turbine performance diagram [4], and the air density is calculated from equations (2) and (3).

$$P_t = P_W C_P(\lambda, \alpha) = \frac{1}{2} C_P(\lambda, \alpha) \rho A V^3 \quad (1)$$

$$\rho = \frac{P'(pa)}{\bar{R}\left(\frac{j}{kg.K}\right) T(K)} \quad (2)$$

$$P' = P_0 e^{\left(\frac{-ghM}{TR_0}\right)} \quad (3)$$

The Ministry of Energy's guaranteed price for power acquired from wind turbine installations is 10374 Rials/kWh, up 13.17 percent annually over the last seven years [5-6]. Three different proposed systems were investigated. On the global market, a 500-watt Cross-Flow wind turbine costs around $3,000 [7]. One of the appropriate criteria for assessing a project's economic value is using the payback period time (PPT). Figure 2 depicts the PPT for the percentage of turbine price reductions in three cities and three systems.

3. Results and Discussion

According to Fig. 2, only the direct sale system in Ardabil will have the PPT less than the lifetime at current prices. Moreover, the PPT of the direct sale system is less than the on-grid systems in all cities. In other words, the direct sale system is the best option for operating Cross-Flow wind turbines in Iran.

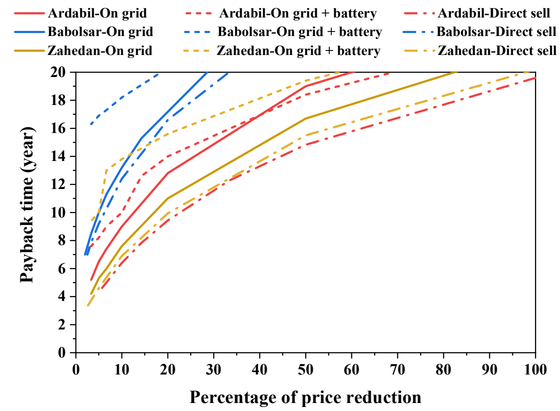

Figure 2 The PPT in terms of percentage of price reduction in three scenarios and three selected cities

4. Conclusions

The present article reviews the studies performed on the design, experiments, and numerical simulations of the Cross-Flow wind turbine.

A Cross-Flow turbine is suitable for urban and home applications because of its low noise, excellent stability, cut-in speed (less than 2m/s), self-starting feature, low height installation capability, and low initial cost.

In addition, the use of this turbine in three Iranian cities (Ardabil, Babolsar, and Zahedan) was explored using three different types of systems (direct sales system, on-grid, and on-grid with batteries). The direct sale system was found to be the best in Iran, and the PPT of less than 10 years is achieved only by reducing the turbine price to 10% to 29% of the current price.

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