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# Development of efficient vertical axis wind turbine clustered farms

Mohammed Shaheen, Shaaban Abdallah

*Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221, United States*

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An efficient triangular shaped three co-rotating Savonius turbine cluster arranged in close proximity shown in Ref. [1] enhances the average output power of its three turbines up to 34% compared to their isolated counterpart. In this study, patterned Savonius vertical axis wind turbine farms are developed for renewable energy generation. The farms consists of multiples of triangular efficient three turbine clusters. The three turbine cluster has a triangular shape and the turbines inside the cluster are arranged in a close proximity to enhance their average output power. The efficient Savonius wind turbine farms are developed using the enhanced three co-rotating triangular turbine cluster of Ref. [1] as the building unit. The developed farms consist of multiple clusters with scaled geometrical ratios of the three turbine cluster keeping the same topology of the cluster. This resulted in patterned farms that have the same power enhancement ratio of the three turbine cluster. Numerical simulations of farms that consist of nine and twenty-seven turbines confirm the enhancement and the pattern progression for larger farms. Numerical results are obtained using Fluent code.



**Contents**



## 1. Introduction

Wind energy is the fastest growing renewable energy source [2]. The global wind capacity was 360 GW at the end of 2014 which provided the world by 4% of its electric energy needs [3]. Horizontal axis wind turbines (HAWTs) dominate the majority of the wind industry, most wind turbine farms consist of HAWTs because of their higher efficiency compared to vertical axis wind turbines

*E-mail address:* mmzs_mtc@yahoo.com (M. Shaheen).

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**Nomenclature**

| | |
|---|---|
| $A_S$ | turbine swept area, $A_S = DH$, m$^2$ |
| $C_m$ | torque coefficient, $T/(0.5\rho V_\infty^2 RA_S)$ |
| $C_{ms}$ | static torque coefficient, $T_s/(0.5\rho V_\infty^2 RA_S)$ |
| $C_p$ | power coefficient, $T\Omega/(\rho V_\infty^3 RH)$ |
| $D$ | rotor diameter, m |
| $d$ | bucket diameter, m |
| $e$ | overlap ratio of the rotor buckets, $e = S/d$ |
| $H$ | rotor height, m |
| $R$ | rotor radius, m |
| $S$ | gap distance between turbines, m |
| $S1$ | cluster height, m |
| $T$ | torque, N/m |
| $T_s$ | static torque, N/m |
| $V_\infty$ | free stream velocity, m/sec |
| $\rho$ | density, kg/m$^3$ |
| $\Omega$ | rotation speed, rad/sec |
| $\lambda$ | tip speed ratio, $\Omega R/V_\infty$ |
| $\theta$ | azimuth angle of the turbine |
| $\alpha$ | oblique angle between rotors |

(VAWTs). A typical HAWT farm has a power densities, defined as the power extracted divided by the area of its foot print, between 2 and 3 W/m$^2$. VAWTs are classified into: lift devices constructed of airfoil blades (H-rotor and Darrieus turbines), and drag devices (Savonius turbines). Experimental researches at CalTech found that the power density of H-rotor VAWT farms can be increased up to 30 W/m$^2$ by optimizing the placement of the turbines that enables them to extract energy from adjacent turbines wakes [4]. The performance of two counter rotating H-rotor VAWTs set at a distance of 1.5*D*–2.0*D* was tested experimentally, an increase of 11% over the efficiency obtained by their stand-alone counterpart was achieved [5]. A geometric arrangement based on the configuration of shed vortices in the wake of schooling fish showed an increase in the performance of an array of 16 × 16 wind turbines by one order of magnitude [6]. Numerical analysis on two-dimensional clusters of VAWTs showed that the performance of turbines operating completely in the wake of other turbines can be improved by choosing their position such that they see a higher flow velocity due to the presence of other turbines and associated stream-tube contraction [7].

This study is interested in Savonius wind turbines which have: simple construction of two or more buckets, independency on wind direction, self starting capability, and they produce low noise levels due to their low tip speed ratio operation [8]. Experimental studies have been carried out to improve the performance of Savonius wind turbine rotor by investigating the effect of the number of buckets, bucket overlap, gap width, shape of the bucket and reduction of the anti-rotation torque of the rotor shaft using curtains or ducts [9–12]. A power coefficient of more than 0.35 was achieved by Savonius rotors with modified geometric designs [12]. Combination of multiple Savonius turbines in close proximity enhanced their power coefficients due to mutual interaction between them [14]. This interaction is a function of the gap distance ($S$) between the rotor tips, relative direction of rotation and relative phase angle ($\phi$) between the rotors. A numerical simulation of a three hydraulic Savonius turbines in a triangular cluster with height 1.6*D*, an oblique angle ($\alpha = 60°$) and tip speed ratio $\lambda = 1$ showed a power coefficient enhancement of 46% relative to an isolated turbine of power coefficient 0.21. Triangular clusters of three co-rotating Savonius wind turbines are studied to obtain the optimum gap distance and oblique [1]. The performance of the clusters showed an enhancement in the average power coefficient up to 34% relative to an isolated turbine of power coefficient 0.23.

In this study, efficient Savonius wind turbine farms are developed using the enhanced three co-rotating triangular turbine cluster of Ref. [1] as the building unit. The cluster with gap distance $S = 2.2D$ corresponding to a triangle height $S1 = 1.6D$ has an enhancement of 25% in the average power coefficient with a ratio of approximately 1:1.2:1 between the power coefficients of its three rotors. Keeping the same topology of the cluster, farms that consist of multiple clusters with scaled geometrical ratios of the three turbine cluster are developed. This resulted in patterned farms that have the same power enhancement ratio of the three turbine cluster. Numerical simulations of farms that consist of nine and twenty-seven turbines confirm the enhancement and the pattern progression for larger farms.

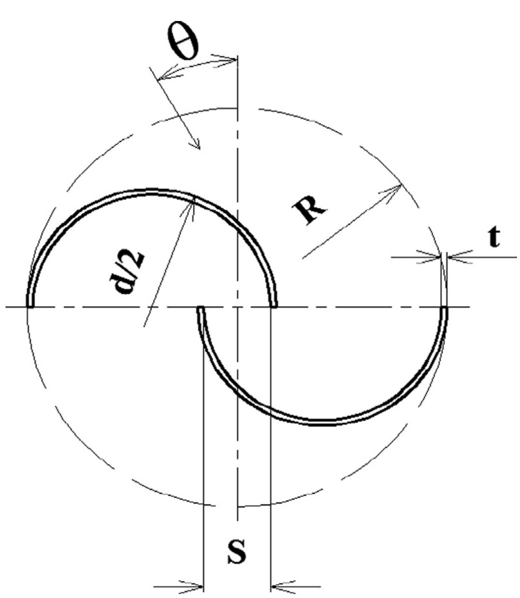


**Fig. 1.** Two bucket Savonius VAWT.

## 2. Numerical simulation model

The Savonius turbine shown in Fig. 1 has a constant cross section. Two-dimensional numerical simulation is performed for a single Savonius turbine [1,13,14], the numerical model is validated by comparing the numerical results with experimental data in Ref. [9]. The same numerical model is used to solve the three cluster and, nine and twenty seven Savonius turbine farms. ANSYS 14.5 workbench multi-physics platform is used to develop a workflow starting from CAD generation, passing by CFD simulation to post-

**Table 1.**
Turbine geometry.

| | |
|---|---|
| **Turbine category** | Vertical axis wind turbine |
| **Turbine type** | Savonius turbine |
| **Number of buckets** | 2.0 |
| **Blade diameter ($D$) [m]** | 1.0 |
| **Blade height ($H$) [m]** | 1.0 |
| **Buckets diameter ($d$) [m]** | 0.525 |
| **Aspect ratio** | 1.0 |
| **Blade thickness ($t$) [mm]** | 1.0 |
| **Overlap ratio ($e = S/d$)** | 0.15 |