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CFD investigation to quantify the effect of layered multiple miniature blades on the performance of Savonius rotor

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ABSTRACT

Present study is focussed on improvement of the coefficient of performance (COP) of a Savonius rotor using numerical simulation software. Quantification of the improvement is based on the comparison of the coefficient of performance (COP) of a basic configuration constituting a conventional Savonius rotor to that of a modified configuration developed by adding concentric multiple miniature blades inside the rotor blades of the basic configuration. Validation and grid convergence studies are carried out using $k-\varepsilon$ and Shear Stress Transport (SST) turbulence models. Validation study suggested Shear Stress Transport (SST) model as more accurate and better option in present study. Shear Stress Transport (SST) turbulence model is used in the numerical simulations of the modified configuration. Optimum level of grid refinement is achieved through grid convergence study. Boundary layer mesh is created on the rotor blades, by estimating distance of first mesh node from the wall using desired values of y^+ for both $k-\varepsilon$ and Shear Stress Transport (SST) turbulence models. An improvement in COP spanning between 8.1% and 11.34% is achieved with the modified configuration.

1. Introduction

In recent decades, global concern over pollution, global warming and possible depletion of non-renewable sources of energy, such as oil has led to exploration of renewable and sustainable energy resources. Conventionally, wind energy is harnessed on large scale using Horizontal Axis Wind Turbines (HAWTs) spread over large area. But the application of Horizontal Axis Wind Turbines (HAWTs) is limited due to requirement of large wind velocities, high initial cost and large area required for their installation [1,2]. The use of unconventional methods of energy generation such as Savonius wind rotors in micro generation is growing, but it is still less widespread. The problem is that it has a low Coefficient of Performance (COP) [3–7]; theoretically $COP \cong 0.18$ [6]. Despite of low power generation capacity, Savonius rotors are gaining popularity among the decentralized power generation methods due to their simple assembly and high starting torque at small rotational speeds [3,8]; low operating costs [9]; easy installation, manufacturing and maintenance [4,9–12]. Savonius rotor is a brilliant design proposed by Finnish inventor S.J. Savonius [5,8,11,13]. Conventional Savonius rotors are drag type hydrokinetic Vertical Axis Wind Turbines (VAWTs). Savonius rotor has low aerodynamic efficiency as compare to Darrieus type wind turbines [7,14]; but still preferable for many applications due to its good starting characteristics [4,15–17]. Also, as it is a VAWT, it can accept wind from any direction because of its omnidirectional characteristics and hence needs no yaw mechanism [7,8,11,17–19]. Many theoretical and experimental studies have been performed by various researchers in the past to improve the aerodynamic performance of the Savonius rotor [8]. Better performance can be achieved by using high aspect ratios [20]; low overlap ratios [21]; end plates [22]; two bladed Savonius rotor rather than three bladed [23]; deflector plate [12,24]; multiple quarter blades [25]. Improvement in the COP is desirable, without compromising the advantages of Savonius rotor and increasing the complexity of design [6].

A cost effective study can be performed using Computational Fluid Dynamics (CFD), saving material and manufacturing costs. The flow through and around the rotor is turbulent. It is very difficult to achieve accuracy in such highly turbulent and transient conditions, so the adopted methodology must be validated to ensure accuracy [6]. Also, turbulence being an important factor in analysis, the prediction of input values of turbulence parameters to be used in the numerical procedure must be done carefully.

Commercial CFD software, Ansys CFX 13 is used to carry out the numerical simulations. This choice was motivated by the availability of licenses for the use of software and the existing practice of its use in the research environment.

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Nomenclature

CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
COP	Coefficient of Performance
DNS	Direct Numerical Simulation
HAWTs	Horizontal Axis Wind Turbines
HPC	High Performance Computing
LES	Large Eddy Simulation
RANS	Reynolds Averaged Navier Stoke's Equations
SST	Shear Stress Transport
TSR	Tip Speed Ratio
VAWTs	Vertical Axis Wind Turbines
VSM	Viscous Sublayer Model
Symbols	
μ	dynamic viscosity of fluid
A	swept area of rotor
C_f'	local coefficient of friction
$degr$	total number of degrees rotated per second
I	turbulence intensity
k	turbulent kinetic energy
l	turbulent length scale
L	characteristic length
q	degrees by which domain is rotated per timestep
N	rpm of the rotor
P_{in}	input power
P_{out}	output power
Re	Reynolds number
R	radius of the rotor
t	length of each time step in seconds
T	torque output
u'	root mean square of the velocity fluctuations
u_{avg}	average velocity of air flow
u_t	friction velocity
V	inlet velocity
y	distance of first node from wall
y^+	non dimensional parameter
β	turbulent viscosity ratio
ε	turbulent dissipation rate
ρ	density of fluid
τ_ω	wall shear stress
ω	specific dissipation rate
ω'	angular velocity

2. Objective

The purpose of present study is to quantify the effect of layered multiple miniature blades on the performance of Savonius rotor. A modified configuration, thus obtained by adding layered multiple miniature blades to the basic configuration; neither alters the maximum space requirements nor the complexity of the basic configuration.

3. Computer Aided Design (CAD) models

A virtual model of the Savonius rotor with same dimensions as two bladed single stage Savonius rotor of Saha et al. [23] is referred to as the basic configuration (Fig. 1) and is used for validation study. A modified configuration (Fig. 2) is prepared by addition of two layers, concentric with the existing blades in basic configuration. Each layer consists of two co-radial miniature blades separated circumferentially by a small distance. Computer Aided Design (CAD) models of basic configuration and modified configuration consist of two domains separated by contact interfaces, in which one large stationary domain representing the surroundings, completely contains the smaller rotating domain as shown in Fig. 3.

4. Governing equations

The equations governing the fluid flow representing conservation laws can be summarised as below [26].

Continuity Equation (Conservation of mass):

$$\frac{\partial}{\partial x_i}(\overline{u_i} + u_i') = 0 \quad (1)$$

where

$\overline{u_i}$ = average velocity of air flow

u_i' = velocity fluctuation due to turbulence effects

x = direction of flow

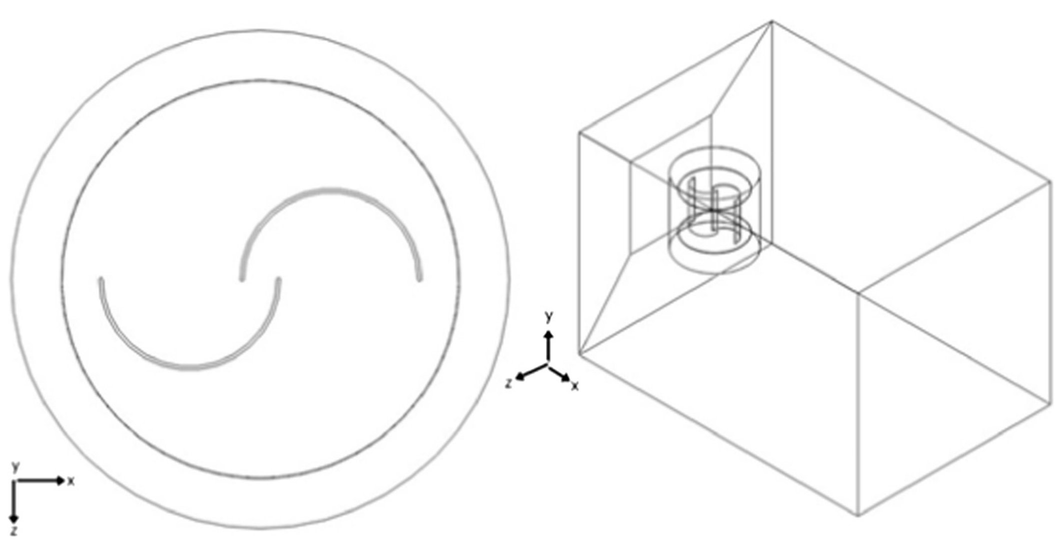

Fig. 1. Basic configuration [23].