Renewable Energy 113 (2017) 461–478

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Performance analysis of a single stage modified Savonius hydrokinetic turbine having twisted blades

Anuj Kumar, Research Scholar *, R.P. Saini, Professor

Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, 247667, India

ARTICLE INFO

Article history:
Received 15 November 2016
Received in revised form
15 May 2017
Accepted 3 June 2017
Available online 6 June 2017

Keywords:
Modified Savonius hydrokinetic turbine
Computational fluid dynamics (CFD)
Power coefficient
Micro hydropower
Numerical modeling
Blade arc angle
Blade shape factor

ABSTRACT

Savonius hydrokinetic turbine is one of the prominent vertical axis turbines for tapping hydro potential available in flowing streams in rivers or canals. In spite of their simple design, Savonius turbines have the problem of poor performance. This study aims to enhance the performance of turbine through modification in the blade shape. Under the present study, geometrical parameters namely blade arc angle and blade shape factor are considered to modify the blade shape of Savonius hydrokinetic turbine. A commercial unsteady Reynolds-Averaged Navier-Stokes (URANS) solver in conjunction with realizable k-ε turbulence model has been used for numerical analysis. Using CFD analysis, blade arc angle and blade shape factor are optimized on the basis of coefficient of power. Fluid flow distributions found around the rotor has also been analyzed and discussed. Based on the present investigation, the maximum power coefficient value of 0.426 is obtained for blade arc angle of 150° and blade shape factor of 0.6 corresponding to TSR value of 0.9 at flow velocity of 2 m/s.

1. Introduction

Since last couple of decades, intensive research has been stimulated for development and promotion of renewable energy generation due to combination of social, environmental and economic interests. Shifting to renewable energy can ensure for reliable, timely, and cost-efficient delivery of energy without environmental threats. Renewable energy technologies have also been serving as economical sources of electricity for rural and remote areas since last couple of years. To produce electricity in such area, hydropower is emerged as most cost effective, efficient and reliable solution. But large-scale hydropower generation is always criticized because of its negative environmental impact while small scale hydropower generation is considered as environmentally friendly technology. Therefore, due to clean, sustainable and locally available, harnessing naturally-occurring high energy flows (i.e. river stream, canal flow) is the best alternative to electricity the rural areas [1]. This kind of generation is known as in-stream hydrokinetic energy production [2]. Hydrokinetic technologies have their geneses in wind energy extraction technologies. Hydrokinetic turbines can also be set up for a wide range of applications including industrial outflows, irrigation canals, rivers and tidal streams [3]. In order to harness energy from river or canal, turbines are broadly classified into two categories i.e. axial-flow turbines and cross-flow turbines [4]. Horizontal axis turbines are more expensive for small power applications [5]. Guney and Kaygusuz [6] reported that vertical axis turbine is more suitable for the cases of limited water flow rate. Khan et al. [7] also stated that vertical axis turbines can be installed either as a single unit in small rivers or stacked together in large rivers. Several advantages i.e. less expensive, independent of flow direction, easy installation and maintenance are driving the intensive research into the design and development of improved vertical axis turbine. Savonius turbine (semi-circular), Gorlov turbine (helically shaped blades), Darrieus turbine and H-shaped Darrieus (straight blades) are the popular turbines in the category of vertical axis turbines [8].

Savonius hydrokinetic turbine, drag-type rotor starts rotating at very low fluid velocity as compared to the conventional hydraulic turbine. It has an ability to accept fluid from any direction with good starting characteristics at low speed. Despite such advantages, Savonius hydrokinetic turbines face low efficiency and large static torque variation [3]. In the last couple of decades, a lot of studies including experimental, numerical studies were carried out to enhance the power coefficient of Savonius hydrokinetic turbine. Khan et al. [9] tested experimentally single and multi-stage Savonius hydrokinetic turbine in a water channel for Reynolds numbers

* Corresponding author.
E-mail address: anuj.iitr02@gmail.com (A. Kumar).

http://dx.doi.org/10.1016/j.renene.2017.06.020
0960-1481/

Nomenclature

H	Height of turbine
D	Diameter of turbine
D_0	Diameter of end plate
q	radius of circular arc
p	straight edge of the blade
ψ	Blade arc angle
α	Twist angle
ω	Angular velocity of rotor
C_P	Coefficient of power
Λ	Tip speed ratio (TSR)
U	Free stream velocity
C_M	Coefficient of moment
$\overline{\Omega}_{ij}$	is the mean rate-of-rotation tensor viewed in a rotating reference frame with the angular velocity ω_k
S	assumed source terms
k	turbulent kinetic energy
ε	dissipation rate of the turbulent kinetic energy
P	density of fluid
u_j	velocity components
x_j	Cartesian coordinate
T	time
μ	viscosity
μ_t	turbulent viscosity
σ_k	constant of the standard k-ε turbulence model
G_k	generation of turbulence kinetic energy due to the mean velocity gradients
G_b	generation of turbulence kinetic energy due to buoyancy
Y_M	is the effect of the changing dilatation in compressible turbulence to the overall dissipation rate

ranging from 0.98×10^5 to 1.96×10^5. The maximum coefficient of power for single stage, two stage, and three stage Savonius rotors is reported as 0.038, 0.049 and 0.04 respectively. Nakajima et al. [10] carried out an experimental study to test Savonius water turbine for Reynolds Number of 1.1×10^5 and reported the maximum power coefficient of 0.25. Further, single stage and double stage (with 0° and 90° phase shift) Savonius water turbine have been investigated experimentally to visualize the flow field around the rotor [11]. The study concluded that double stage rotor with 90° phase difference produces 10% larger power coefficient. Golecha et al. [12,13] reported the improvement in coefficient of power by using deflector plate. The coefficient of power is improved by 50% with the deflector plate on the returning blade side and 150% with deflector plates on the both blade side respectively. Yaakob et al. [14] investigated conventional Savonius water turbine numerically, and maximum C_P is reported as 0.275 at TSR of 0.7, which were in good agreement with the experimental results. Kumar and Saini [15] carried out numerical investigation to improve the power coefficient by using twisted blade profile.

The literature review as mentioned above emphases on the studies carried out on Savonius hydrokinetic turbine. In earlier studies, the problem of having low efficiency of Savonius wind rotor have also been addressed by modifying blade shape like modified Bach, Benesh, semi-elliptical [16–18]. However, no information is available on modification of blade shape in case of twisted bladed Savonius hydrokinetic turbine. Hence, there is a need to analyze the effect of blade arc angle and blade shape factor on the performance of twisted blade Savonius hydrokinetic turbine in an open channel flow.

In order to study the effect of blade arc angle and blade shape factor on the performance of twisted blade Savonius hydrokinetic turbine, unsteady and rotating 3D CFD simulations are carried out under the present study. It is, therefore, the objectives of the present study are as follow:

1. To study the effect of blade arc angle on the performance of twisted Savonius hydrokinetic turbine
2. To investigate the effect of blade shape factor on the performance of twisted Savonius hydrokinetic turbine
3. To study the velocity and pressure distributions across the turbine under different velocity conditions.

Under the present study, commercially available software ANSYS 15.0 is used. ANSYS workbench provides a platform to develop a workflow, starting from generation of 3D CFD model, mesh generation, setting fluent solver to results analysis in CFD-Post. This software is widely used to simulate the flow around the turbine. In order to accomplish the proposed objective, the procedure adopted under the present study is given in a flow chart as shown in Fig. 1.

As shown in Fig. 1, the component of optimization process is carried out by determining the optimal value of blade arc angle (ψ) and blade shape factor (p/q). In order to obtain the maximum value of C_P, blade arc angle varied for a given value of fixed blade shape factor (p/q). The simulations have been carried out for different values of TSR for a given range of flow velocity. Corresponding to maximum value of C_P, the blade arc angle is identified as optimal arc angle. On similar lines, for a given value of blade arc angle, the blade shape factor is optimized.

2. Parameters investigated for Savonius hydrokinetic turbine

Under the present study, the geometrical parameters considered are blade arc angle (ψ) and blade shape factor (p/q). The schematic view of Savonius hydrokinetic turbine having twisted blades along with geometrical parameters considered (ψ and p/q) for the study is presented in Fig. 2. Blade cross section keeps on changing certain degree in each step along the vertical axis (z-axis) in the case of twisted blade profile as shown in Fig. 2(iv).

Table 1 gives geometrical parameters of twisted blade Savonius hydrokinetic turbine considered for numerical simulations. Optimized twist angle for Savonius hydrokinetic turbine was reported as 12.5° in an earlier study [15], and same is taken for the present study. In order to study the effect of blade arc angle (ψ) and blade shape factor (p/q), Table 2 presents configurations considered in the present study.

Under the present study, the range of water velocity is considered as 0.5 m/s to 2 m/s. A cylindrical shape encompassing the turbine is created which represents a rotating zone of the domain for numerical simulations. In other studies [19–21], the size of a rotating zone has been considered as 1.28 times of turbine diameter to 3 times of turbine diameter (1.28D-3D). The diameter of the rotating zone is considered as 1.5D for the present investigation. Computational domain similar to an open channel having dimensions of 0.55 m × 0.65 m × 3.0 m is also designed for numerical investigation. This domain has water surface similar to open channel flow; the normal water level in the channel is set at 0.65 m. Savonius hydrokinetic turbine is considered to be completely