The renewable energy generated by the Savonius wind turbine used for water extraction

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Abstract: - In this paper a numerical study of the flow through a Savonius vertical axis wind turbine was carried out using CFD methods. It's well known that this type of wind turbine operation has unsteady effects which include the creation and separation of vortices. Romania has a good potential to use renewable energy for agriculture, mostly for crops irrigations. Even if this type of wind turbine has poor efficiency - compared with Darrieus types - it can be used for water extraction because it has a high torque at small wind speeds.Two dimensional simulations were used to assess the unsteady flow around vertical axis wind turbine. Because Reynolds number is low a transition SST turbulence model was chosen. The numerical results confirm that an URANS solver can describe with good accuracy the detached flow structure around the Savonius type vertical axis wind turbine. Vorticity magnitude field for several TSR values are presented and the implications discussed.

Key-Words: low speed wind, renewable energy, VAWT, Savonius, URANS, high torque

1 Introduction

Wind energy is considered a very promising renewable energy source, estimating to cover 20% of the global electrical energy demand by 2020 [13]. Is an inexhaustible and renewable source available almost anywhere on the planet [9].

Almost half of European Union area is covered by farmland. Even in the most developed countries, the economic activity of agriculture is subject to the forces of nature which sometimes surpass the factors and phenomena related to human activities [7].

Remarkable increase of agricultural load due to concentrative irrigation arrangement will consume a large amount of energy and impact the operation of power system [17].Wind power, as a source for irrigation, becomes attractive due to its wide availablility and the low costs of wind energy [11].

Also, due to the environmental and economic reasons, the world needs alternative sources of energy. To contribute to the environment protection and solve the ever increasing demand of energy it is important to use any source for renewable energy in an efficient way. This can be made possible by using advanced wind turbines.

A wind energy conversion system is especially attractive for agricultural applications because it can provide direct mechanical shaft power that minimizes the conversion losses for applications such as pumping, grain grinding, drying and mixing etc. [14].

The shortage of electricity power in the developping countries as a result of insufficient power generation makes conventional electricity availability unreliable for irrigation of crops [5].

As such, small wind energy turbines had become very important in many developing countries. Small wind generators can cover the energy needs of an entire farm [13]. However, the cost per unit of electric power generated from small turbines is greater that of the larger ones.

Vertical axis wind turbines have the advantage of always facing the wind, which makes them a significant solution in our quest for cheaper, cleaner renewable sources of electricity [12]. Various vertical axis wind turbines can provide the energy requirements ranging from 2 kW to 4 MW with a reasonable payback period [1].

Savonius turbines are one of the simplest VAWTs. They are drag-type devices, consisting of two or three scoops. The differential drag is converted to torque. Because they are drag type devices, extract much less of the wind's power than other similarly-sized lift-type turbines [2].

During the '60s and '70s, Savonius was considered as an example of appropriate technology for rural development in the third world due to its low maintenance requirements [17].

The Savonius rotor is particularly useful for situations that do not require a high outputs of electric power [6]. It has good starting characteristics, relatively low operating speeds; low noise; high starting torque, self-starting at low wind speed and an ability to accept wind from any direction and has proven itself very useful for applications such as pumping water for irrigation in rural areas, agitating water for aeration of ponds, small scale household wind turbines [16].

Savonius rotor can also be used for converting water current to electrical energy. Much larger Savonius turbines have been used to generate electric power on deep-water buoys, which need small amounts of power and get very little maintenance [4]. Savonius rotors are used whenever cost or reliability is prevalent [3].The Darrieus turbine on the other hand, is having high efficiency and tip speed ratios beyond unity, needs to be coupled to a generator that converts its high speed into electric power which in turn runs a pump. [10]

Savonius and other vertical-axis machines are good at pumping water and other high torque, low rpm applications and are not usually connected to electric power grids [2] but rather connected directly to various types of water pumps [8].

2 Problem Setup

The Savonius wind turbine, is a VAWT which relies on the drag difference between the blades to obtain the torque. One of the advantages of this type of wind turbines is that it is omnidirectional and at lower wind speeds has a good starting torque. Its rotating axis is perpendicular to the wind direction. This turbine efficiency is slightly lower compared to other types of wind turbines operating on lift, however, the constructive simplicity often outweigh the efficiency.

Figure 1 represents the Savonius wind turbine type researched and developed by COMOTI which will be tested in the experimental base at the Black Sea shore, where the average wind speeds reach 8-9 m/s.

Fig. 1 Savonius wind turbine

The wind power equation for a vertical axis wind turbine is:

$$P = \frac{1}{2}\rho S V^3 C_p \quad (1)$$

where ρ – air density (kg/m^3), S – rotor swept area (m^2), V – wind velocity (m/s), C_p – power coefficient.

Also, the power available from wind can be written as:

$$P = M\omega \quad (2)$$

with ω – angular velocity (rad/s) and M - rotor torque (Nm) given by:

$$M = \frac{1}{2}\rho C_m l S V^2 \quad (3)$$

Power coefficient C_p , for a wind turbine is the ratio of the extracted power from the wind to the available power.

$$C_p = \frac{M\omega}{\frac{1}{2}\rho S V^3} \quad (4)$$

The power coefficient C_p and the torque coefficient C_m can be determined as a function of tip speed ratio TSR. Tip speed ratio represents the ratio of the blade tip speed to the wind speed [15].

$$TSR = \lambda = \frac{\omega R}{V} \text{ , } R - \textit{rotor radius [m]} \quad (5)$$

$$C_p = \lambda C_m < \frac{16}{27} = 0.59 \quad (6)$$

The maximum value of the power coefficient is $C_p = 0.59$. Only less than 60% of the wind energy can be converted into mechanical power [10].

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2.1 CFD Setup

In this present study the analysis was performed with the commercial software ANSYS Fluent, to determine the aerodynamics coefficients as well as the power and torque of the turbine.

The tested wind turbine is a two-blade rotor, half cylinders displaced from each other with a gap. The flow inside the rotor is influence by the overlap ratio. The gap distance is $e = 0.2$ m and wind speed is equal with 10 m/s.

The geometrical parameters of the Savonius rotor are presented in Table 1.

Table 1: Geometrical features for Savonius wind turbine

Parameters		Value
Diameter	D[m]	3.3
Height	H[m]	3.3
No. of Blades	N[-]	2
Blade's Chord	c[m]	1.65
Gap	e[m]	0.2
TSR	λ[-]	0.2-1.2
Angular velocity	ω[rad/s]	1.21-7.27
Wind Velocity	V∞[m/s]	10

The computational domain was divided into two regions: the rotor domain which cover the blades and the outer domain, with an interface between them.

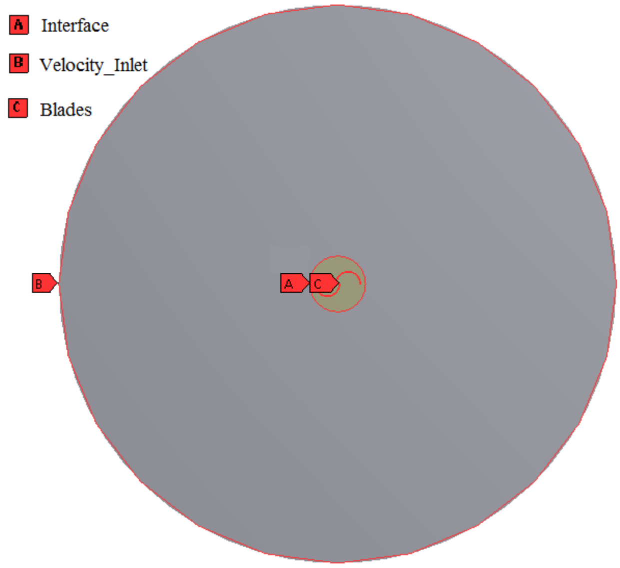
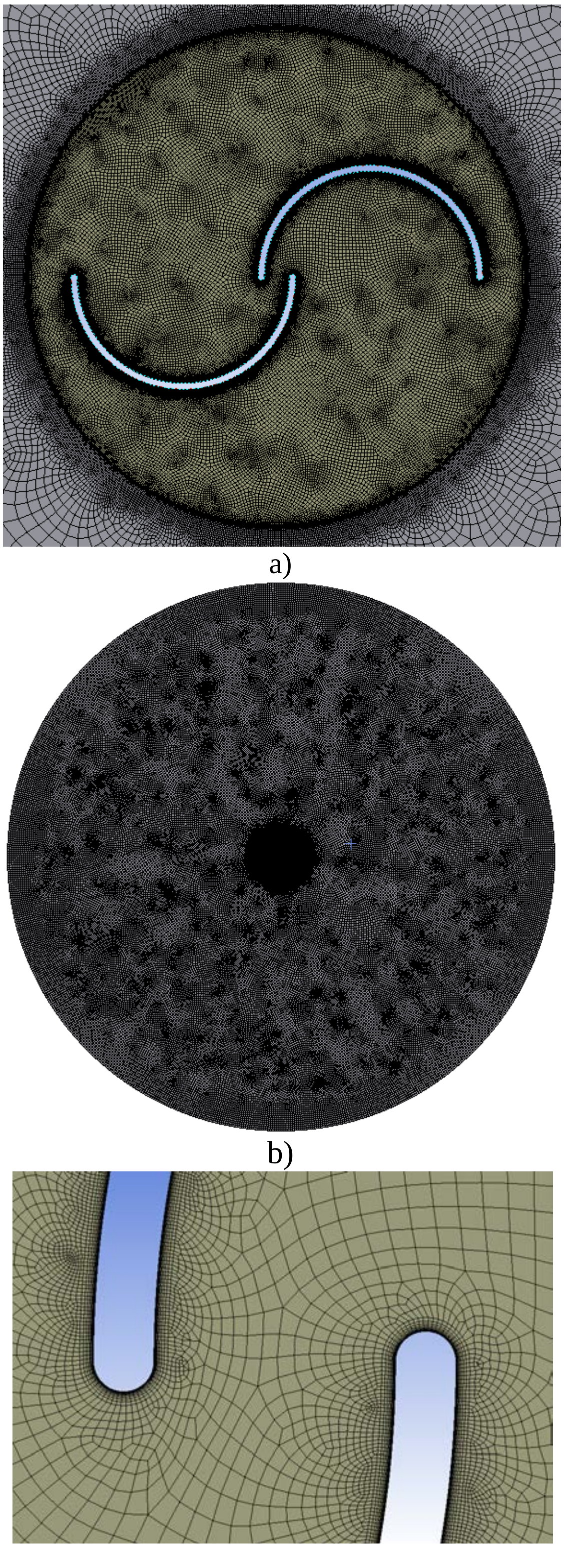


Fig. 2 Boundary conditions for the computational domain

2.2 Spatial discretization

The two domains were discretised with quadrilateral elements. In Figure 3 a) the grid for the rotor domain is denser than for the outer domains.

Near the blade, the minimum cell it set to achieve the value of y^+ around 1.



a)

b)

c)

Fig. 3 Grid generation a) rotor domain b) outer domains c) around the blade

2.3 Turbulence model

In these simulations an URANS model was used to study the flow around Savonius wind turbine. Because the flow has a low Reynolds number the SST transition turbulence model was used.

This model was proposed by Menter [19] and has four equations which allow it to solve the problems from the transition regime between the laminar and turbulent region, adding to the classical SST model, two more transport equations.

Transport equation for kinetic energy (*k*):

$$\frac{\partial k}{\partial t}+\overline{u}\frac{\partial k}{\partial x}+\overline{v}\frac{\partial k}{\partial y}+\overline{w}\frac{\partial k}{\partial z}=$$

$$=\frac{1}{\rho}\left[\begin{array}{l}\frac{\partial}{\partial x}\left(\Gamma_k\frac{\partial k}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_k\frac{\partial k}{\partial y}\right)+\\+\frac{\partial}{\partial z}\left(\Gamma_k\frac{\partial k}{\partial z}\right)\end{array}\right]+ \quad (7)$$

$$+\tilde{G}_k-Y_k\,.$$

Transport equation for specific dissipation rate (*ω):*

$$\frac{\partial \omega}{\partial t}+\overline{u}\frac{\partial \omega}{\partial x}+\overline{v}\frac{\partial \omega}{\partial y}+\overline{w}\frac{\partial \omega}{\partial z}=$$

$$=\frac{1}{\rho}\left[\begin{array}{l}\frac{\partial}{\partial x}\left(\Gamma_\omega\frac{\partial \omega}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_\omega\frac{\partial \omega}{\partial y}\right)+\\+\frac{\partial}{\partial z}\left(\Gamma_\omega\frac{\partial \omega}{\partial z}\right)\end{array}\right]+ \quad (8)$$

$$+G_\omega-Y_\omega+D_\omega\,.$$

The intermittent transport equation:

$$\frac{\partial(\rho\gamma)}{\partial t}+\frac{\partial(\rho U_j\gamma)}{\partial x_j}=P_{\gamma 1}-E_{\gamma 1}+P_{\gamma 1}-E_{\gamma 2}+$$

$$+\frac{\partial}{\partial xj}\left[\left(\mu+\frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial \gamma}{\partial x_j}\right] \quad (9)$$

The transport equation for the momentum thickness Reynolds number $\tilde{\mathrm{Re}}_\theta$:

$$\frac{\partial\left(\rho\tilde{\mathrm{Re}}_\theta\right)}{\partial t}+\frac{\partial\left(\rho U_j\tilde{\mathrm{Re}}_\theta\right)}{\partial x_j}=$$

$$=P_\theta+\frac{\partial}{\partial x_j}\left[\sigma_\theta(\mu+\mu_t)\frac{\partial\tilde{\mathrm{Re}}_\theta}{\partial x_j}\right] \quad (10)$$

3 Results

In this section the quasi-two dimensional simulation results from the numerical CFD simulation are presented. All analyses were done with the unsteady SST transition turbulent model. To determine the operation conditions the tip speed ratio (TSR) values, the variation domanin was between 0.2 and 1.2.

In numerically determining the efficiency of the vertical axis wind turbine Savonius type, we plotted in Figure 4 the torque coefficient variation and in the Figure 5 the power coefficient for various values for TSR. Also in Figure 6 are shown variations of vorticity for each case study.

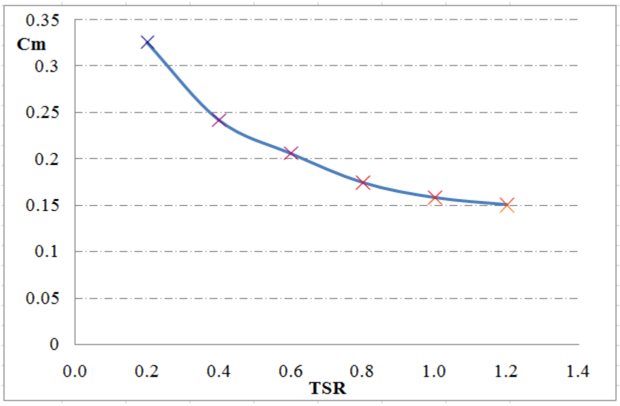


Fig. 4 Torque coefficient variation with tip speed ratio (TSR)

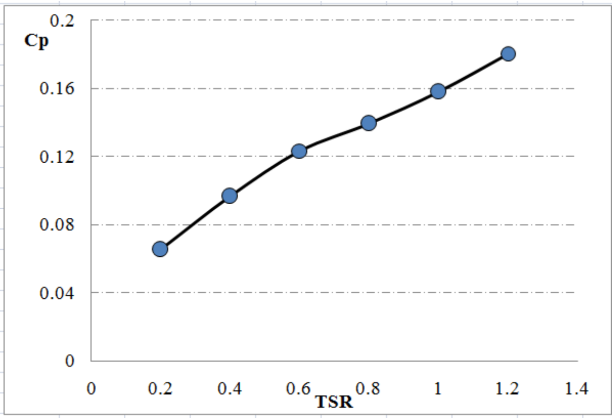


Fig. 5 Power coefficient variation with tip speed ratio (TSR)

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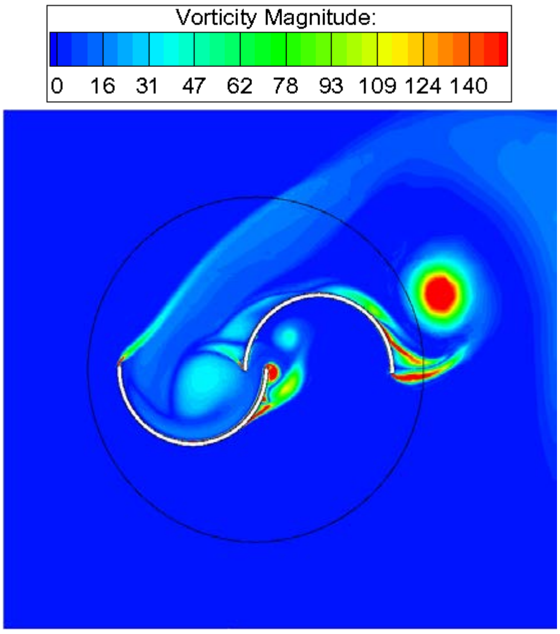
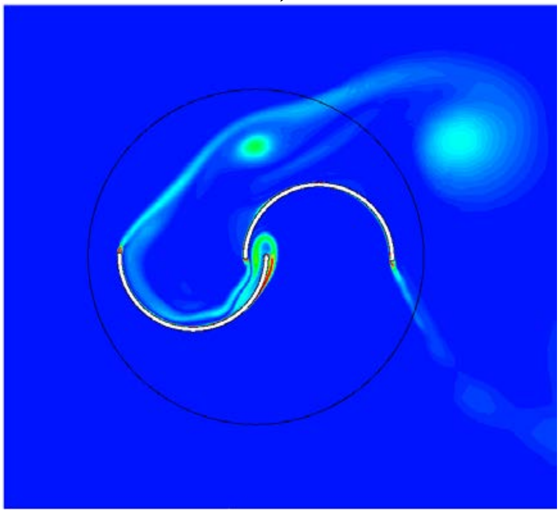


a)



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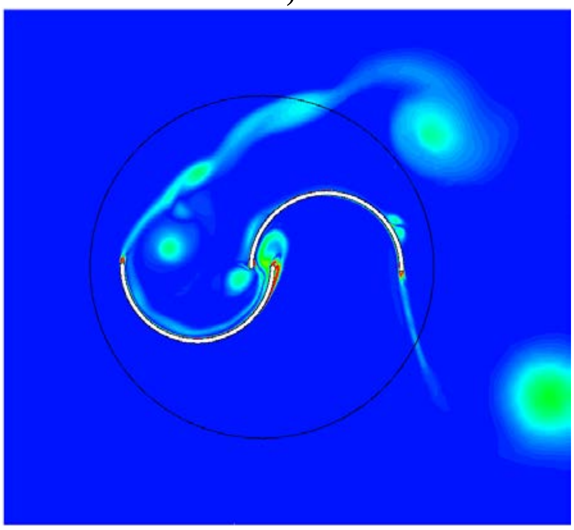

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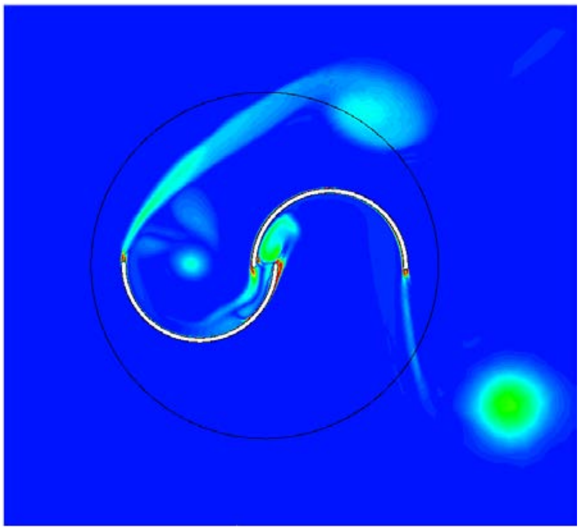

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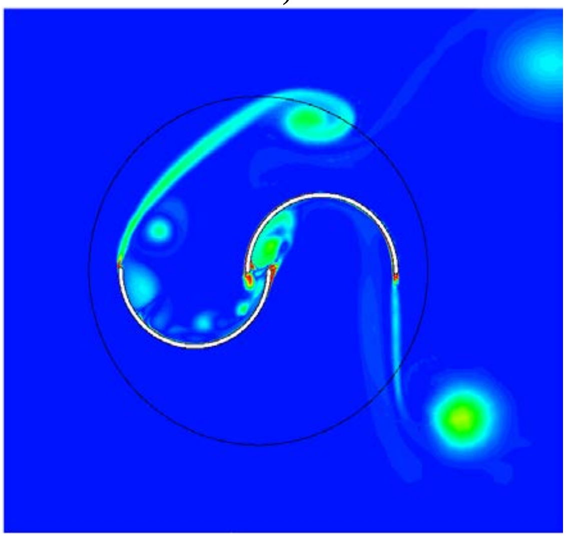
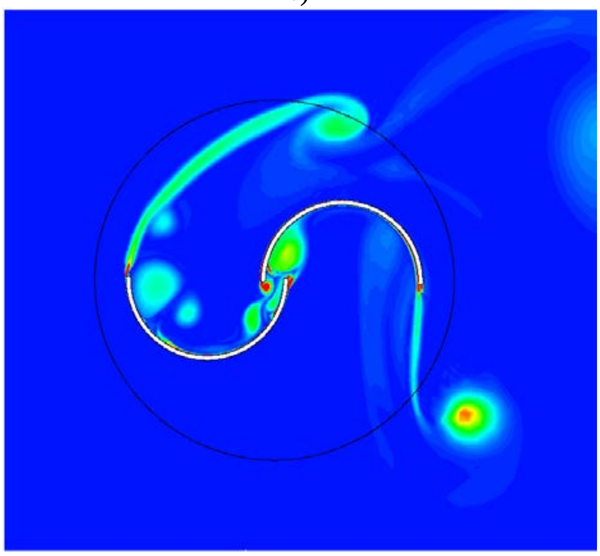


e)



f)

Fig. 6 The vorticity distribution for TSR:
a) 0.2; b) 0.4; c) 0.6; d) 0.8;
e) 1.0; f) 1.2;

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4 Conclusion

The purpose of this paper was to determine numerically the efficiency of a vertical axis wind turbine of Savonius type which can be used for water extraction. This machine can be useful in agriculture field where the water extracted by this device will be used in the crop irrigation. The URANS 2D simulation was perform with the Ansys Fluent commercial code for CFD analysis. In this study we use values for TSR ranging from 0.2 to 1.2 and 10 m/s wind velocity. As results the vorticity magnitude for each case was presented in this paper. Also the torque and power coefficient variation was determined in this study. This geometry will be tested in the COMOTI wind tunnel to validate the numerical results.

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