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COMBINED WIND TURBINE WITH ADJUSTABLE BLADES

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Abstract—*Carried out analysis of existed vertical axis wind turbines. Considered the combination of Savonius and Darrieus type vertical axis wind turbine with adjustable blade applying.*

Index Terms—Savonius wind turbine; Darrieus rotors; adjustable blade.

I. INTRODUCTION

Wind is an environment friendly source of energy that has got huge potential of satisfying the energy needs of people and mitigating the climate change from greenhouse gases, emitted by the burning of fossil fuels. It was estimated that roughly 10 million MW of energy are available in the earth's wind [1]. The potential of wind energy is reflected in the increase of capacity growth of wind energy systems. As of now, the installed capacity of wind energy system in the world is 194.390 MW. Wind can be tapped by wind turbines that convert its kinetic energy into mechanical power, which is in turn converted into electricity by generator of the wind farm. Wind turbines are of two types, Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). VAWT is mostly viable for places with low wind speed regimes where HAWT is highly uneconomical. Further, VAWT rotors do not require any yawing facility that brings the plane of the blades to the wind direction, as required in case of HAWT. However, the major drawback of VAWT is its low performance coefficients. Hence there is a scope for major research on VAWT rotors to improve their performance. The present work is based on VAWT rotor. VAWT rotors are of different types, like Savonius, helical Savonius, Eggbeater Darrieus, H-Darrieus, combined configurations of Savonius and Darrieus rotors etc.

In this report, we propose a Darrieus-Savonius combined turbine to improve the small starting torque of a Darrieus turbine since a Savonius rotor generates large torque in the low speed range, whereas the Darrieus turbine generates large torque primarily in the high speed range. First, the hydrodynamic force of the semi-circular section which is used as the bucket of the Savonius rotor was measured in a wind tunnel. Then, the torque of the rotational axis of the Savonius rotor in four configurations of two buckets was measured in a circulating water channel. From the results of the tests, we adopted a configuration of the Savonius rotor to combine with the Darrieus turbine with two wings. We measured the torque of the combined turbine in the circulating water channel, altering the attaching angle between the Darrieus wing and the Savonius bucket. We confirmed the improvement of the starting torque of the combined turbine, but at the same time we found that the maximum torque at the high rotational velocity ratio was decreased by 30 % compared with the torque by the solo Darrieus turbine. To solve this problem, a ratchet mechanism or one way clutch mechanism between the Darrieus turbine and Savonius rotor was tested to avoid the negative torque which might be generated by the Savonius rotor.

II. DESIGN OF COMBINED ROTOR

The Figure 1a shows a typical Savonius wind rotor, which consists of two semi-cylindrical blades placed together in such a way that they form an S-shape, resulting in having two concave and two convex sides adjacently. Figure 1b illustrates the working principle of a Savonius rotor, when exposed to wind; a concave and an opposite convex sides of the rotor will always be facing the wind; this in turn creates a difference in drag forces exerted by the impinging wind on the curved blades, causing the rotor to rotate around its axis. Savonius rotor generally has two blades; however, several experimental investigations have been carried out to analyze the performance of rotor with different number of blades. M. Hadi Ali (2013) conducted experiments for a Savonius rotor with two and three blades in order to investigate the effects of different number of blades on its performance. It was concluded that with the increase in number of blades; reverse torque increases as result net torque acting on the blades of rotor decreases. Therefore, Savonius wind turbine with two blades had higher power coefficient than three bladed Savonius wind turbine under similar test condition. N.H. Mahmoud and A.A. El-Haroun investigated several parameters affecting the performance of Savonius rotor including: different number of blades, staging, end plates, aspect ratio as well as overlap ratio. It was found that the rotors with end plates had better aerodynamic performance than rotors without endplates also the efficiency improved with the increasing aspect ratio. Double stage rotors had higher performances than single stage rotors.

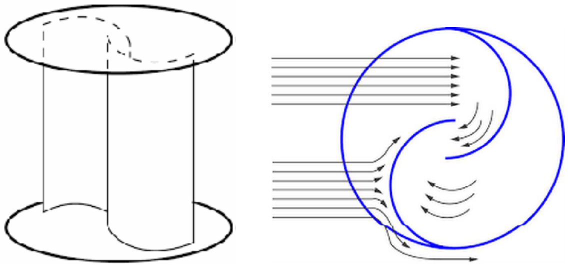
a b

Fig. 1. Savonius wind turbine (a) typical Savonius rotor (b) working principle of Savonius rotor

Georges Jean Marie Darrieus, a French Engineer in 1931; invented the VAWT named Darrieus wind turbine. It was a US patent under the name “Turbine having its rotating shaft transverse to the flow of current” consisting of two different configurations: Straight bladed type and Curved bladed type as illustrated in Fig. 2a and 2b.

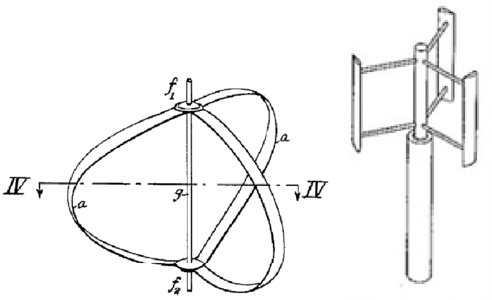

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Fig. 2. Patented Darrieus rotors (a) Egg beater type; (b) H-type

The turbines in Fig. 2a and 2b are generally known as Eggbeater type and H-type Darrieus, respectively. Eggbeater Darrieus type wind turbine has a troposkien shape. It possesses some advantages over H-type Darrieus. The curve shape minimizes the bending stresses experienced during centripetal acceleration while rotating; allowing for a better distribution of fluctuating aerodynamic loads. Eggbeater Darrieus is also associated with various disadvantages including; complex and expensive blade design as well as vulnerable to dynamic stalling. Dynamic stall effect on the aerodynamic performance of the VAWTs blade was studied by Scheurich F. el. at. It was concluded from the study that straight blades have uniform local angle of attack distribution throughout the blade’s span in contrast to curved blades and is easier to construct. A typical straight-bladed Darrieus wind turbine consists of 3–4 straight blades; connected to either a main link from center or supported by two main links at the top and bottom.

The Darrieus rotors are aerodynamically lift based devices, thus can rotate faster than the wind. These devices are used for power generation due to their high RPM rating, however they are not self-starting and have lower starting torque as well as dynamic stalling makes them less reliable in areas with weak prevailing wind.

Figure 3 shows the first prototype made by combining the Darrieus type of wind turbine with Savonius wind turbine. There are three pieces of Darrieus type blades, and one unit two level Savonius wind turbine.

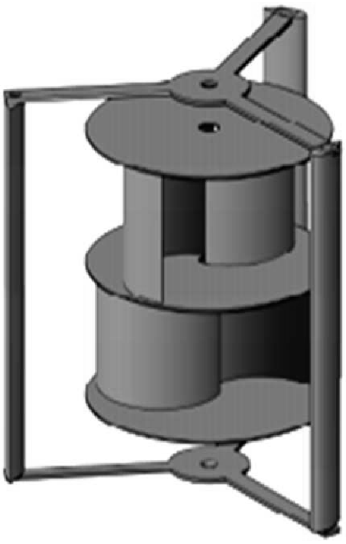

Fig. 3. Layout of Darrieus–Savonius VAWT

The electric generator (including mechanical break system) was installed below the entire blade system. The wind turbine has some defects during the first run. The defects are the wind turbine swing in some specific rotational speed and the shaft is categorized as soft shaft (the natural frequency is beneath the operation condition). Therefore, it needs some modifications. The best optimization implies less swing motion, more sturdy and shifting the first natural frequency of VAWT system lower than the original design.

III. APPLICATION OF BLADE ADJUSTMENT

The control strategy describes the control technogies used at various wind speeds and indicates the purpose they serve. Shown in the Fig. 4 are five different ranges of wind speed, which require different speed control strategies descibed below.

In the Fig 5 shows the input signal used in simulations.

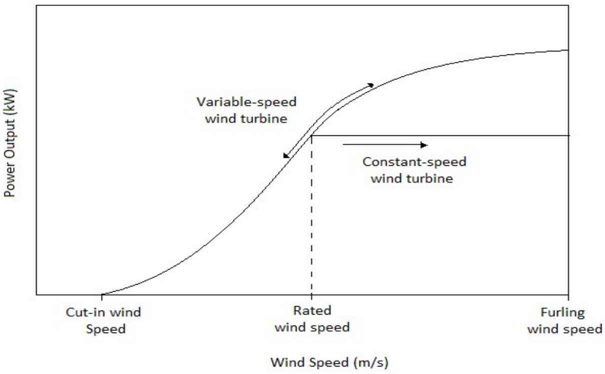

Fig. 4. Typical power vs. wind speed characteristics of variable speed wind machines

1) Cut-in speed is the speed below which the machine does not produce power. If the rotor has a sufficient staring torque, it may start rotating below this wind speed. However, no power is extracted and the rotor rotates freely. In many modern designs the aerodynamic torque produced at the standstill condition is quite low and the rotor has to be started (by working the generator in the motor mode) at the cut-in wind speed.

2) At normal wind speeds, maximum power is extracted from wind. We have seen earlier that the maximum power point is achieved at a specific (constant) value of the TSR. Therefore, to track the maximum power limit point, the rotational speed has to be changed continuously in proportion to the wind speed.

3) At high winds, the rotor speed is limited to maximum value depending on the design limit of the mechanical components. In this region, the Cp is lower than the maximum, and the power output is not proportional to the cube of the wind speed.

4) At even higher wind speeds, the power output is kept constant at the maximum value allowed by the electrical components.

5) At a certain cut-out or furling wind speed, the power generation is shut down and the rotation stopped in order to protect the system.

The last three control regimes can be realized with pitch angle control (if these are installed), and eddy-current or mechanical brakes.

In this chapter, three models have been discussed for a pitch actuator system.

The three models are:

1) proportional Control;
2) constant pitching speed;
3) PID Control.

All these models are tested against a standard pitch angle input signal which is shown below.

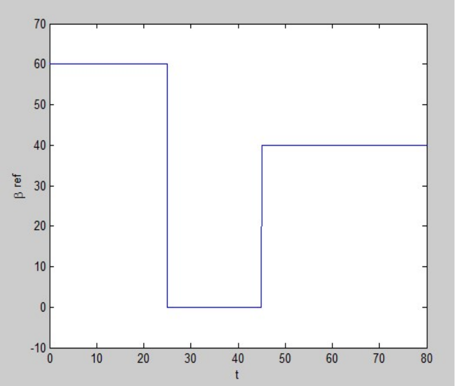

Fig. 5. Input used in simulations

A. Proportional Control based Pitch Actuator System

The Simulink model (Fig. 6) for the proportional conrol system is shown below. The input is received as input which is passed through a saturation filter. The purpose of the saturation filter is to limit the pitch input within the range of –3 degrees to 90 degrees which is the range of valid pitch angle values. Next comes the gain block defining the proportional gain of the system. The block named RL2 is also a saturation filter which is defines the limiting values of pitching speed. The maximum and minimum permissible value of pitching speed in this system are 8 degrees per unit time and –8 degrees per unit time respectively.

The response of this system has been observed for four different values of proportional gain (Fig. 7).

B. Pitch Actuator System with constant value of pitching speed

This model was suggested by Yousif El-Tousin his paper “Pitch Angle Control of Variable Speed Wind Turbine,” 2008. In this model, he suggests that the pitching speed of the blades be kept constant. This way, the actuator system is not only simple but the stress on the blades is also considerably reduced. The main disadvantage of the first version actuator is that we cannot predict which pitch angle will be needed at that time when the actuator has reached command value. At this time the wind condition may have changed and then we will need another setting. The second version compare 'on line' the proper criterion and then decide, if to increase or decrease the pitch angle, without predicting the future angle like in the first version (Fig. 8).

The response of this system has been observed for three different values of pitching speed viz. 5 deg/s, 8 deg/s, and 15 deg/s. The result of these tests has been shown below. It can be seen that if the pitching speed is set too low, it cannot effectively track the input signal causing an error to prevail at all times. Also a very high value of pitching speed demands a very high torque to be exerted on the blades which may lead to undesirable stresses on the blade and actuator (Fig. 9).

C. PID Control based Pitch Actuator System

The third model which has been studied is the PID control based Pitch Actuator System (Fig. 10). The gains of the PID controller are changed one at a time and the response has been noted. The Simulink model for the actuator has been shown below.

As can be seen, the system produces a decent response in the first case where the gains are $K_p = 2$, $K_i = 0.01$ and $K_d = 0$. The general approach is that the values of gains, once set, are not changed. An adaptive PID approach has been proposed where the values of gains are revised after every step of input based on the time response parameters (Fig. 11).

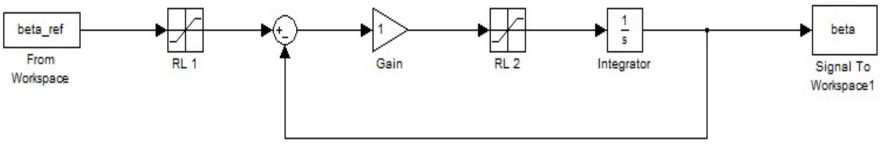

Fig. 6. Block Diagram of Proportional Control based Pitch Actuator System

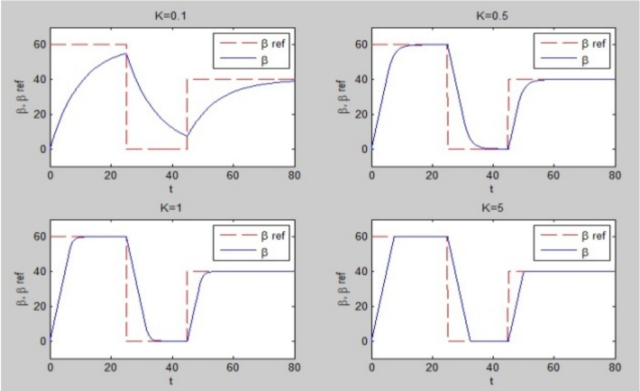

Fig. 7. Pitch angle response of Proportional control based Pitch Actuator System

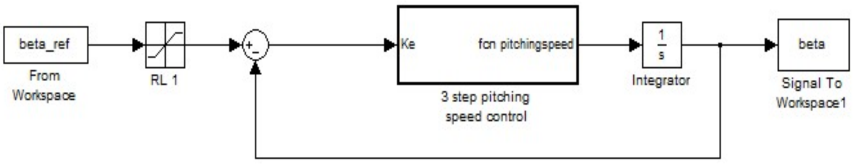

Fig. 8. Block Diagram of Pitch Actuator System with constant pitching speed

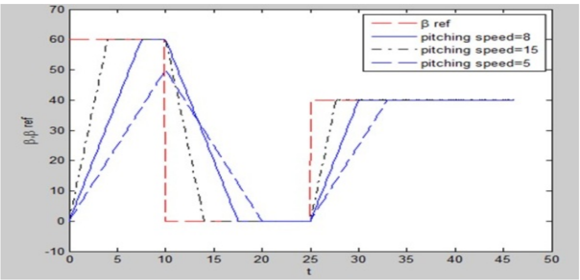

Fig. 9. Pitch angle response of Pitch Actuator System with constant pitching speed

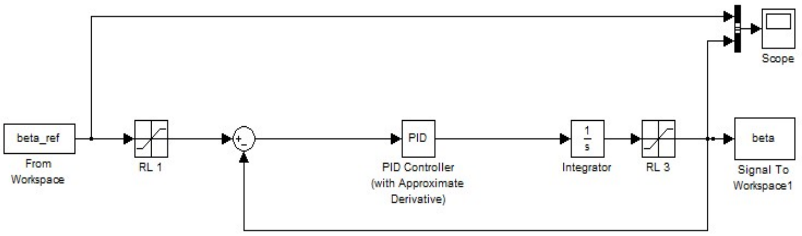

Fig. 10. PID Control based Pitch Actuator System

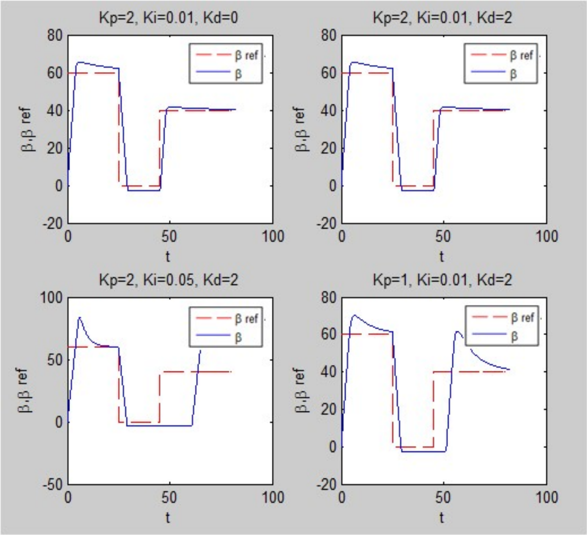

Fig. 11. Pitch angle response of PID Control based Pitch Actuator System

Wind Turbine Model

As mentioned before, the power contained in the wind is given by:

$$P = \frac{\rho A}{2} v_{\text{wind}}^3,$$

and the electric power generated by the wind turbine is given by:

$$p_m = C_p(\lambda, \beta) \frac{\rho A}{2} v_{\text{wind}}^3.$$

IV. CONCLUSION

In this paper, an attempt was made to measure the performance of a three-bladed combined Darrieus–Savonius rotor with Darrieus mounted on top of Savonius rotor, for overlap variations from 10.8% to 25.8% in a low TSR range.

The present Darrieus–Savonius rotor can be suitably placed in the built environment where it can harness more power from wind and, at the same time, would self-start in low wind condition prevalent in such environ ment.

The power coefficient is a function of pitch angle and tip speed ratio. The following model has been used to approximate the relation of C_p with Tip Speed Ratio (TSR) and pitch angle

$$C_p(\lambda, \beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)^{e^{\frac{-C_5}{\lambda_i}}} + C_6\lambda,$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1},$$

where C_p is the power coefficient; β is the pitch angle; λ is the tip speed ratio; $C_1 = 0.5176$; $C_2 = 116$; $C_3 = 0.4$; $C_4 = 5$; $C_5 = 21$; $C_6 = 0.0068$.

The power characteristics of the above model has been shown in Fig. 12.

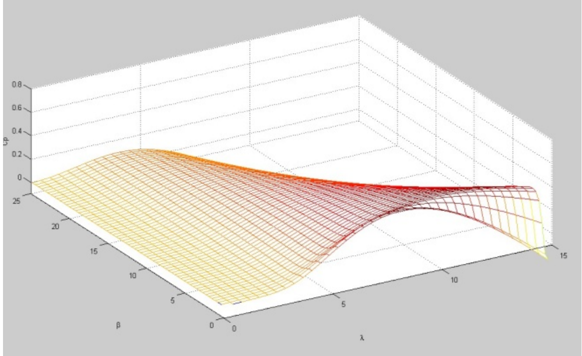

Fig. 12. Power Characteristics of Vertical Axis Wind Turbine course, there are some small errors in the results, but they are not significant

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В. М. Синєглазов, І. С. Швалюк. Комбінована вітроенергетична установка з поворотними лопатями

Проведено аналіз існуючих вертикальних вітроенергетичних установок. Розглянуто комбінований ротор Дар'є та Савоніуса із застосуванням поворотних лопатей.

Ключові слова: ротор Савоніуса; ротор Дар'є; поворотна лопать.

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Напрям наукової діяльності: аеронавігація, управління повітряним рухом, ідентифікація складних систем, вітроенергетичні установки.
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В. М. Синеглазов, И. С. Швалюк. Комбинированная ветроэнергетическая установка с поворотными лопастями

Проведен анализ существующих вертикальных ветроэнергетических установок. Рассмотрен комбинированный ротор Дарье и Савониуса с использованием поворотных лопастей.

Ключевые слова: ротор Савониуса; ротор Дарье; поворотная лопасть.

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