Electrical Power and Energy Systems 103 (2018) 395–403

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Developing the full-field wind generator integrated with the vertical twin rotors

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ARTICLE INFO

Keywords:
Full-field wind generator
Normal rated power
Vertical twin rotor
Starting wind speed

ABSTRACT

This research aims to develop a full-field wind generator integrated with a vertical twin rotor that the applied generator uses a variable normal rated power and driven by a vertical twin rotor. This developed windmill is with a complex structure which combines both Savonius and Darrieus blades. During the working process, the Savonius blade is driven by a slower wind speed and promotes the Darrieus blade to reduce its starting wind speed. The Darrieus blade then drives the electric generator. Rotation of the two blades will be separated in a high speed wind field to reduce the wind resistance of the windmill. The efficiency of multi-layer magnetic electric machine can achieve to 84% at 200 rpm, 81.1% at 300 rpm, even 80% at 400–900 rpm. Also, the automatic control load has a better efficiency which is a 3% difference compared with the fixed load operation and the maximum efficiency can be up to 19.11%.

1. Introduction

It is well known that wind energy is one of eco-friendly and fastest growing energy resource with huge potential gained from the nature [1,2]. The wind energy driven boats along the Nile river were invented as early as 7000 years ago. Water was pumped by windmill in China at 200 BC. In the 1950s, the wind electric turbines still can be found in Denmark but were ultimately sidelined becuase of cheap oil and low energy prices. However, the massive carbon release causes global warming and servere climate change which breaks the environmental balance. With the advances of science and technology, the demand of green energy has arisen and caught more attention in the past decades. However, the unstable production yields great difficulties. To improve the quantity and the quality of green energy, there have ben various strategies and techologies developed [3–8].

Wind turbine electric generator in general are categorized in two basic types: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) [9,10]. HAWTs have been commonly found near the land and coastal area, however, the HAWTs has few disadvantage such as stronger tower construction required and high cost of transportation and installation. This is because the turbine size needs to be huge to increase the power efficiency [11] and the space between these turbines must be large to avoid the flow interference caused by adjacent turbines [12]. Comparing with the HAWTS, the VAWTs are prefered in urban area because of smaller scale, less demand of space, easier maintenance, lower cost, and less noises [11]. Among various VAWTs, it can be categorized in two types: drag-type wind turbines and lift-type wind turbines. The Savonius is one of the drag-type wind turbines [13] and the rotation speed is relatively low under resistance, and they are typically found in wading and irrigation [14]. The Savonius wind turbine is usually low-cost and can be started at low wind speeds [13]. The Darrieus turbine is a lift-type wind turbine and more commonly seen, and these sheet-like blades eliminate at high speed due to the centrifugal force generated by bending [15]. The efficiency is higher, but it is relatively difficult to start with.

Due to the extreme climate in Antarctica area, all wind turbine designs should be considered strictly. Mats Wahl uses finite element analysis (FEM) in the H-rotor design which helps the wind turbine design economically and more time saving [16–18]. Also, blade type is one of the key factors in turbine blade design, and the airfoil is the most commonly used type. The NACA 0018 has a good performance in lift coefficient which leads to a better working efficiency [19]. To enhance the strength and the quality of the turbine blade, a composite material-carbon fiber is used in the blade production since it allows a better turbine performance and turbine load reduction.

The complex vertical axis wind electric generator usually puts the Savonius blades inside the Darrieus blades. However, it is found that the inside Savonius blade operation airflow will interfere the outside

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https://doi.org/10.1016/j.ijepes.2018.06.003
Received 2 January 2018; Received in revised form 4 May 2018; Accepted 1 June 2018
Available online 18 June 2018

Darrieus blade operation to cause a low operation speed and low working efficiency. The rotational speed will drop to 50–100 rpm while the wind speed is 6 m/s. The conventional wind electric generator generally works with a fixed normal rated power (NRP) and is the electromagnetic induction generator, whereas an electric generator with large NRP also receives relatively small working efficiency while the input power is too small. In previous research, the conversion efficiency can be as high as 42% [20,21].

For the past years, the CCT lab which was built in Taipei Tech by Professor Chen-Cheng Ting has been developing harvesting techniques and wind energy related applications since 2005. Discovering new applications of wind energy and improving working efficiency of windmill system are two of main group objectives. In 2008, a new application of wind forced chiller was introduced which first connected the windmill to the air-conditioning field. The dual system of wind chiller integrated with wind generator to enlarge total working efficiency of the windmill system after three years [22]. A multi-layer magnetic cut electric generator can achieves the best efficiency under different rotation speeds. In 2012, Chiu [23] modified the coil winding method and applied the idea of full wind field to automatically switch the load and make the working efficiency up to 19.6% which is a 3% increasement compared to the constant-load type. The objective of this research is to propose a novel idea in which the Savonius blades are installed above the Darrieus blades so both of them can't interfere each other. Also, under the one-way bearing principle, a sleeve is made to initialize the Savonius blade which drives the Darrieus blade rotation and decreases the wind turbine machine starting wind speed. Also, a multi-layer magnetic cutting electricity generator is integrated with the full-field wind vertical twin rotor to produce the electric power.

2. Theoretical analysis

To convert the wind energy into the electricity, an electromagnetic induction generator is often applied due to its relatively high working efficiency and long lifetime duration. This work develops the full-field wind generator integrated with the vertical twin rotor. The working principle is detailed in this section.

2.1. Analysis of wind turbine efficiency

The theoretical maximum wind turbine efficiency can reach up to 0.59 in terms of the Betz limit [27]. Most of the wind turbine efficiency and operation speed varies as the wind speed changes. Also, if any further air resistance or friction on the blade body considered, the efficiency will be even lower than the theoretical maximum value. Measuring the total working efficiency of the wind electric generator uses the natural wind energy as the input power. Analysing working efficiency of the electric generator uses an idler to pre-save the input energy. Thus, the input power P_{in} is defined as:

$$P_{in} = \frac{dW}{dt} = \tau\omega, \tag{1}$$

$$\tau = I_m\alpha, \tag{2}$$

$$I_m = \frac{1}{2}mr^2, \tag{3}$$

where W is the work, t is the time, τ is the torque, ω is the angular speed, I_m is the rotational inertia, α is the angular deceleration, m is the mass, and r is the idler radius. Eqs. (1)–(3)receives

$$P_{in} = \frac{1}{2}mr^2\alpha\omega. \tag{4}$$

Moreover, the output power P_{out} from the electric generator is:

$$P_{out} = IV, \tag{5}$$

where I is output current and V is output voltage of the electric generator. Therefore, working efficiency of the electric generator η_e is:

$$\eta_e = \frac{P_{out}}{P_{in}} \times 100\%. \tag{6}$$

The power obtainable from a cylinder of fluid with cross sectional area A and velocity v is

$$P = \frac{1}{2}\rho A v^3 C_p, \tag{7}$$

where ρ is the air density, A is the swept area of wind turbine, v is the wind speed, and C_p is the coefficient of power. The reference power for the Betz efficiency calculation is the power in a moving fluid in a cylinder with cross sectional area A and velocity v:

$$P_{wind} = \frac{1}{2}\rho A v^3, \tag{8}$$

The coefficient of power C_p is then derived as:

$$C_p = \frac{P}{P_{wind}} = \frac{2I\alpha\omega}{\rho A v^3}. \tag{9}$$

2.2. Blade solidity

To design a wind turbine blade, there are two different areas should be considered. One is the blade area and the other is the swept area of the windmill. The blade solidity (σ) is considered as one of the most important design parameter for the axial flow impeller [24]. For horizontal axis windmill, the solidity is defined as the ratio of blade area and swept area of windmill. Fig. 1 shows the blade solidity definition of the vertical axis windmill. For vertical axis windmill, the solidity is defined as the ratio of th blade chord length to pitch, which is listed as follows [25]:

$$\sigma = \frac{ND}{2\pi R}, \tag{10}$$

where N is the number of blades, D is the chord length, and R is the turbine rotation radius. Solidity ratio generally falls in the range of 0.4–1.1.

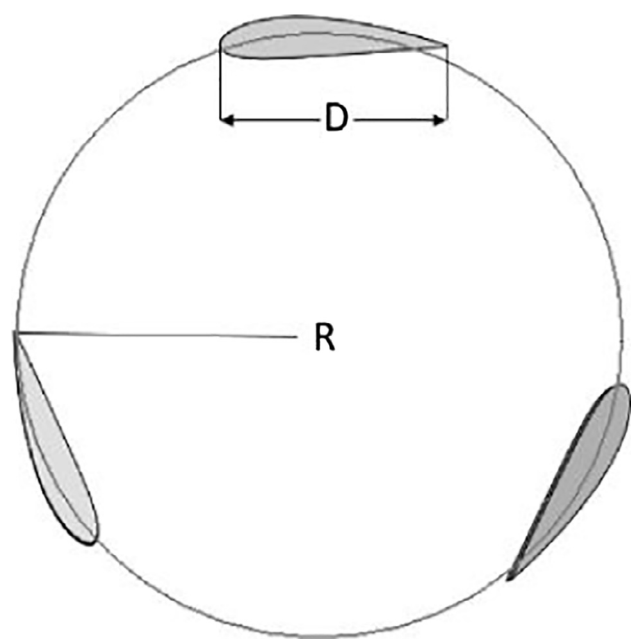

Fig. 1. The schematics of blade solidity definition of vertical axis windmill.