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VARIABLE GEOMETRY DARRIEUS WIND MACHINE

J.T, PYTLINSKI AND D. SERRANO

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J.T. Pytlinskit and p, serraict®

Cunter for Energy ana Envivonment Re

University of Puerto Rico

Mayaguez, Puerta Kice 50709

ABSTRACT

Anew variable geometry Darrieus wind machine is proposed. the jouer attachnent of the blades to the rotor san move fiaely wp 88g, down the axle allowing the blades to change snape during po- tation. Experimental data for «17m diametes Darsteus fagge? 3nd 2 theoretical model for multiple streantube perforsance pre- diction were used to develop a computer simulation proses for studying parameters that affect the machine's porforaance, ?Sew structural and éynamic parancters were incorporaced ate the Program and varied in order te simulate the machine's overtion An a wide range of aerodynamic conditions.» tn comucacione t Parabolic blade was used to approximate a true troposhein shape.

The computer simulation study shows that governor: behavios er a Darrieus turbine can not be atcained by a standard turbine opere ating within normally occurring rotational velucity linitss These results are illustrated graphically and nuresically, A Second generation variable geonetry Darricus wind tussiae which

uses @ telescopic blade is proposed as @ potential improvenene

on the studied concept

KEYWORDS

Wind power; vertical~axis wind turbine; Dersieus wind turbine of

Yariable geometry; theoretical analysis; conpurer similstion rer

sults.

Mead and Senior Scientist, Solar Division

**Graduate Student

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IWTRODUCTION

ttached to the rotor at two ends. The Darric gus machine was reintroduced again in the mid-1960's by research=

EFS Of the National Research Council of Canada (NRC). "Since then theoretical aspects of Darrieus turbine operation have been studied in detail by NRC and Sandia Laboratories in the United States. Their research has shown that the machine has aerodyra-mic characteristics which in some respects differ from those of other wind machines; that it has a greater energy output ser

The Darrieus machine differs by several features from convention-al windmills which rotate about a horizontal axis. the tesbine which is usually composed of two or three blades, is omiaicse tional and accepts wind from any direction without yauning,

axle is held vertically by guy cables, the
turbine does not need to be placed on a tower to keep the blades high above the ground. Moreover, the generator and gear tears do not need to be elevated and ate mounted on the ground. These features simplify the maintenance and repair of the machine cos. ponents.

Yet, the Darrieus wind machine is not self-starting. Its fixea-pitch blades stall at low speeds and they cannot be depended upon to drive the turbine from a standstill. To operate the Darrieus machine as self-starting, one or two Savonius rotors are mounted on the center shaft to propel the turbine at iow wind speeds, or an auxiliary motor provides a starting torqee. The Darricus machines usually operate at constant revimin by being connected to a utility grid through a synchronous gengra~ tor.

The Darricus turbine uses lift as a driving force and is consi-Gerably more efficient than drag turbines such as the Savoniuss Zt is, however, generally less efficient than propeller driven wind machines." Darrieus wind machines Tanging from a few kilo~ watts to 250 kW are used, instead of diesel engines, to pump water and generate electric power in renote locations of Canada, the United States, Australia, New Zealand, Argentina and other countries. ?Research is being done to impfove the aerodynamic Performance of the turbine and to develop machines in the mega-watt range.

NEW VARIABLE GEOMETRY DARRIEUS WIND TURBINE

In a standard Darrieus turbine, the tip to speed ratio? varies

along the rotor blade from a peak near the biete mid-point to near zero where the blade joins the toraue axle. ?Consequently

re

The ratio of the blade tip speed to wind speed.

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this ratio cannot be optimal along the entire length of the blade. The turbine geometry results from the shape imposed on blades that are permanently attached at both ends during a wide Fange of aerodynamic conditions and that are shaped to sininice bending stress. In a standard turbine the blade is curved Like 2 fee-spinning rope or troposkein that would allow centrifugal forces to act throughout the length of the blade. In practices hovever, the blades do not assune a troposkein shape. "During Fotation factors imposed on the machine such as energy outpuc Per unit of mass, tip to speed ratio, aspect ratios end solidity? determine the shape of the blade during rotation. In a varia ble geonetry turbine, however, the blades assune a shape impos- ga by the turbine operation conditions and by the centrifuge) forces acting on the bledes. In a standard turbine and. in?s variable geometry turbine the blades are fixed in pitch. Tn both, the blades have the sane cross section from one end to the other. Therefore, they can be extruded and mass-produced,

Figure 1 shows a conceptual drawing of the new variable geome-

tty Darrieus wind turbine. In this turbine the lower ateachment

Of the blades to the rotor axle is free to move up and down,

Fig. 1. New variable goonctry Darrieus wind turbine

with structural spring.

ratio of the turbine height to its dianeter.

The

2 the ratio of the blade area to area swept by tarbine.

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TEs motion occurs because of variations in the turbine angular

Velocity caused by different wind conditions and the subsequent

Yariation of the turbine monent of inertia, centrifugal foven

mic conditions of the turbine operation, Two concepte were son

in the first concept, the blades thenselves act as

spring as shown in Fig. 1; in the second concept,

an external spring is added as shown in Fig. 2.

Fig. 2. New variable geometry barrieus wind

turbine with external spring.

THEORETICAL ANALYSIS

Several theories using a single streantube, multiple streantub OF vortex models have been developed to evaluate the perfore Rance of a vertical axis wind turbine (Strickland, 1975, 1976) Wilson, 1976; Blackwell, 1975, 1977; Klimas, 1978, 1900; ayaa 2983; Paraschivoi and belciatx, 1983). ?The majority of these theories are based on monentun and blade element techniques and gesune the turbine is enclosed in a single streamtube with unic form cross-sectional conditions or contained in a number of streantubes, each with different conditions, Airfoil theory is vsually used to determine the effective uind velocity on the blades. The theory generally usga to nore correctly predict changes in the power coefficient® produced by different wind speeds is the multiple streamtube theory. This theory is less

?The ratio of actual power output to theoretical output.

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Eomplex than the vortex theory and allows for variations in blade geonetry and wind shea: effects. In consequence, the multiple streantube theory (Strickland, 1975) was selectea for Geveloping a computer ?simulaticn program co study the paramevers that affect the performance of a variable geometry Darricus wind turbine.

iable Geonetry Modi

The basic streantube theory (Strickland, 1975) was adopted to analyze the performance of the new variable geometry barrieus Bachines shown in Figs. 1 and 2. The variable geometry model uses parabolic blades (Blackweil and Reis, 1975), a8 af approxi= mation for the troposkein blades (Blackwell and Reis, 1979), Using the coordinate system in Fig. 3 and the general equation for a parabol,

1)? = 4p end a

an expression for the radius in terms of the vertical coordinate

@ was derived:

3)

aah

Fig. 3. Rotor geometrical para

From equation (2) the blade radius for a given height can be de-

termined. Because the angle § (see Fig. 3) varies with the

changing geonetry of the blades, this variation can be deter~

mined as well by finding the angle made by the slope of the

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blade curvature at the radine x with the horizontal Line.

Since tans = #2 the derivacive $2 of equation (2) leads to the expression for 6:

:

2 2

seen Gee $F a

Qcher Paraneters of the parabola such as swept area, are length,

Tonent of inertia about the axis of rotation and radius of sere:

tion have also been determined (Blackwell and Reis, 1395) ack

can be listed as follows:

1. Swept area:

oe ?w

Are length:

1

2}

B80 ee Pe ne ay

Pa : (5)

3. Moment of inertia about axis of rotation:

2,2

(san?) 5 3 3

1, = oy RA ra-3,-25.4.

a ey Ray (SE isa?" Yes? * op

1,4

Ge + 6)

2 ea?

where:

Be

4, Radius of gyration:

2

FogR om

Bach blade is treated as a parabolic beam which has one fixed

end, is loaded uniformly, aad whose deflection is being governed

by centrifugal forces according to the following expression

(Tuma, 1365,

«)

= Young's modulus of elasticity for blade material

= cross section moment of inertia of the blade along

the chord line.

*

1

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The load on each segment along the blade chord line results

from the centrifugal acceleration a. acting on the blade ead is defined by the expression: 7

sagt (vy) ru? «

where:

Pp 7 specific density of blade material

Vg ? volune of blade segment

?The load can then be expressed in terms of F_ with the uniform

dy distributed mass as follovs: ©

Ys

(0)

where:

S = arc length of parsbol

The uniformly distributed 1cad was approximated in the computer simulation work by using the lead acting at the radius of ays

ration

Mp Ye) Bp oF ay

You =

Both the structural spring (see Fig. 1) and the external spring

{see Fig. 2) experience the sane deflection § when subject? to

the load Wa...

pg Ny tan(r-e8)

oo «ay

be

where

Ky = Kop + Kop? total spring constant

Ky = Kop because &,

= 9> Kop

?sp

and

Kyq 7 structural spring constant

Xgp = external spring constant

RESULTS OF COMPUTER stMvLATION

Variable parancters such as structural and dynamic aspects of

the Darrieus wind machine described above have been incorpor

ted into the computer program to simulate the work Of an peteal

machine in a wide range of aerodynamic conditions. To deter~

mine the dynamic aspects of the machine's behavior unger simala~

ted conditions, several assumptions were made

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* Blade is treated as beam of parabolic shape working

within the elastic limit of its material

* Total load Wy contributes toward the blede's deflection 6

? Mechanical friction at the axle due to turbine rotation

3nd the varying geometry of the blades is negiiginic

* Head resulting from the gravitational forces is negligible.

?The calculation process consists of the following steps:

1. Load on the blade ie determined by using as sssused value

of the angular velocity of the turbine

2+ Deflection of blades is computed from equation (12) by

assuning different values for Key

3. New value for the turbine height is computed from:

Hee Bag &

fnew ? Pore

4+ Anew equatorial radius, R, which corresponds to Ris

computed by using Newton-Raphson method

5. New moment of inertia I, is computed trom equation (6)

&- Power coefficient, C,, variation with tip-to-speed ratio,

TSR, is determined by using the multiple streantube

theory.

formance, such as solidity and tip-to-speed tatio Tek, there Paraneters and variations of w vs H, and uve TGk were snes computed.

Computations were done for the Darrieus wind machine that has ihe, following characteristics (Worstell, 1981); turbine herant Zea B (55-8 ft), turbine diameter = 16.7 m (34.5 fern any

187 me (2014 ft), arc length = 24.1 m (79 ft), bie fase ¢ 323 kg (713 ibm), ?chora length ~ 0.533 » (1/95' fer ber of blades = 2 or 3,?aerofoil section = NASR OJI>) Sy puter simulation program was run for the values of = 108 A= 20.645 in?, R, = 0,3 x 10°, cy and Cp, taken for? the values Of the angle of attack a which was calculated according to the multiple streantube theory.

Tee computer program was checked out by computing the variation of the coefficient of performance, C,, versus tif-to epecd ratio. TSR, for the Darrieus wind machine having the paraneters above. | it was found that the reaults agreed well mith shee obtained elsewhere (Worstell, 1961) -

(36:33 ft). Such deflection is unacceptable seructusally.

During the change in the machine's geometry the solidity value Gecreased from about 0.13 to below 6.10 which ied to a t1iohe @ecrease in the peak value of the machine's power coctfiniene,

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Tighin the rotational velocity values used (up to 69.57 rev/min), fhe change in turbine geometry, although large, was not sufficient to make the turbine regulate its speed by ecting like 2 govecen.

To control the Darrieus turbine goonetry within acceptable blade Structural limits and to dampen possible oscillations, wn entece pal spring was added 2s shown in Pig. 2. ?The competes simante fiom vas done for different external spring constants ranging from K = 3000 to K = 30000. As chown in Fig. 4 the turbine

7 Kx: 20000

12.

13.

na

76:

7

SS th bib iteiaiat

26 9 12 15 18 at 2m ar x

TSR

Fig. 4. Variation of Darrieus turbine angular velocity w (ft/s)

with tip-to-speed ratio, TSR, for spring constant KS

30000 ané K = 70000; N,'= 2,'c = 0.533 m (1,75 in).

geometry is almost fixed for K = 30000 and varies very little

for higher values of K. The results indicate that by selecting

a, PEoper spring constant (see Figs.5 and 6) the blade Geflec-

tion can be reduced to reasonable limits. The solidity varia

Eon is almost the same as for the former concept with? a ctrec-

tural spring constant. Although the turbine responds to che

Yariation in rev/min iike a governor, as shown in Pig. 9, enen

Feplacing K = 30000 by K = 3000 in the computer simulation pro

gram, the machine operation paraneters are even farther away

from reaching governor conditions because the change in scoke-

fry is smaller than for the concept shown in Fig. i for the

2imits of w used in computations. As can be seen, the curve on the figure changes its shape for different % values and ulti-

mately may bend and reach a plateau at higher values of o snd

TSR when governor operation conditions are reached.

This first generation variable geometry Darrieus wind machine

led to a second generation turbine which is now being investi~

gated. the concept allows the turbine to increase its radias

by almost two-thirds of its initial value by using telescopic

Blades. it is expected that the machine will respond sore

Like a governor. The use of a variable spring constant may be

warranted to control the turbine gecmetry within @ broader

range of operation parameters. The solidity will vary from

O-13 0 about 0.08 which for R= will fesult in & stronger

Cy variation. %

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wo

m

we

1

"s 1.3000

7%

s

? 1

° pt pe

© 4 8 42 35 20 24 28 32 a6 40

Fig. 5. Variation of bareiens turbine radive R(ft) with an~

gular velocity uo (te) for K = 3000 and KS Seonny

Ng = 2, C © 0.533 m (1.78 anj

wy

~ 65

76

38

?

0

© 6 2 18 24 30 26 42 48 54 00

4

19200

Fig. 6. Variation of Darrieus turbine neight, (ft), with an-

gular velocity w (ft/s) for K = 3000 and K = 300005

Ny = 2, C= 0.533 m (1-75 in}.

Wore spreadout optimum values are ex,

pected for C, vs TSR as

shown in Fig. 8 (Strickland, 1975). °

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Skee:

concussions

The variation of turbine geometry dur

not change the turbine moment of ince

$$ @ governor. Therefore the turbine

its rotational velocity

the increase of the turbin.

the peak value of the coc!

tening of the curve Cvs

spreading out the optimum ¢, throughout

ing normal operation does

tia enough to make it act

can aot self-regulate

The decrease of the solidity due to

@ Tadius causes a slicht decrease in

ficient of performance and sone flat=

TSR. This creates a possibility tor

the variable centr:

tural and external springs.

fogether with other structural a

Fesult of this study a new genes

Afugal force can couse oscil Latics

?This effect should be

pects of the blsces.

tion of variable gecnecry

range of TSR values.

ns in struc~

investigated

As the

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Darrieus wind machine with <eJescopic blades is proposed as an alternative to the fixed gecietry machine.

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