

Three Pitch Control Systems for Vertical Axis Wind Turbines Compared

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ABSTRACT

The desirable performance attributes of a vertical axis wind turbine (VAWT) include high starting torque, high peak efficiency, broad operating range and a reasonable insensitivity to the parameters that define its operation. The theoretical performances of three variable pitch mechanisms for VAWT are compared. Cycloturbines use cam devices or gears to impose a sinusoidal pitch regime. In the mass-stabilised system, pitch is determined by the interplay of two opposing moments on the blades. These two mechanisms are compared with "Aero-pitch", a hypothetical pitch control system in which stabilising moments are related to the blade relative velocity.

NOMENCLATURE

Symbol	Unit	Description
A	m ²	Airfoil plan area
c	m	Blade chord length
C _d		Airfoil drag coefficient
C _l		Airfoil lift coefficient
C _m		Airfoil quarter chord pitching moment coefficient
C _p		Turbine performance coefficient
C _{ploss}		Parasitic loss coefficient
C _q		Turbine torque coefficient
F _r *		Non-dimensional blade radial force
F _t *		Non-dimensional blade tangential thrust
J	kg m ²	Blade polar moment of inertia
K _{in}	kg	Aero-pitch parameter opposing pitching of trailing edge inwards
K _{out}	kg	Aero-pitch parameter opposing pitching of trailing edge outwards
N		Number of blades
M _a	N m	Pitching moment on blade
M _{in}	N m	Stabiliser moment opposing pitching of the trailing edge inwards
M _{out}	N m	Stabiliser moment opposing pitching of the trailing edge outwards
M _p	N m	Nett moment causing pitching of blade
m _s	kg	Stabiliser mass
R	m	Turbine radius
U	m s ⁻¹	Ambient wind velocity
Y	m s ⁻¹	Local wind velocity at the blade
W	m s ⁻¹	Blade relative velocity
X _{in}	% blade chord	Moment arm opposing pitching of trailing edge inwards
X _{out}	% blade chord	Moment arm opposing pitching of trailing edge outwards
X _p	% blade chord	Direct distance from pivot point to blade quarter chord
α	rad	Blade angle of attack for zero pitch

β	rad	Blade angle of attack
γ	rad	Blade pitch angle
γ_{off}	rad	Blade offset pitch angle
γ_{amp}	rad	Blade pitch angle amplitude
γ_{in}	rad	Maximum permitted blade pitch amplitude of trailing edge inwards
γ_{out}	rad	Maximum permitted blade pitch amplitude of trailing edge outwards
$\dot{\gamma}$	rad s ⁻¹	Blade pitch angle velocity
$\ddot{\gamma}$	rad s ⁻²	Blade pitch angle acceleration
λ		Tipspeed ratio
ρ	kg m ⁻³	Air density
σ		Turbine solidity = Nc/R
θ	rad	Blade azimuth angle
Ω	rad s ⁻¹	Turbine angular velocity

INTRODUCTION

Previous Attempts at Improving Self-starting

Some fixed pitch configurations of the straight blade VAWT will self-start under zero-load conditions^{1,2}, however none produce enough starting torque to drive positive displacement pumps or air compressors directly, i.e. without a clutch.

Early attempts at improving the self-starting of VAWT concentrated on optimising configurations of static geometric parameters. Turbine solidity, blade camber and thickness, blade offset pitch angle, and blade lean forward (or yaw) angle have been examined with the expectation that combinations of all or some of these parameters will substantially increase desirable characteristics. More recently, blades with trailing edge extensions have been studied. From these investigations a number of general qualitative conclusions can be drawn:

- High solidities tend to provide some starting torque but with lower peak efficiency and narrower operating range^{2,3}.
- Thicker blade profiles seem to contribute to slight increases in starting torque. Peak efficiencies are attained at higher tip speed ratios, and there seems to be little or no effect on operating range^{2,3,4}.
- A judicious choice of blade camber can increase starting torque, but reductions in peak efficiency and narrower operating ranges have been observed^{1,2,5,6}. Small trailing edge extensions seem to further improve the starting torque with little further degradation of peak performance or operating range⁶.
- Offset pitch angle can increase starting torque, however peak efficiencies seem to occur at lower tip speed ratios⁷.
- Blade yaw angle can affect the blade stall angle and should improve starting torque¹.

Despite some of the individual performance gains, there seems to be nothing in the literature that suggests that combinations of these static geometric parameters would allow consistent starting under load, high peak efficiency, and a wide operating range.

VARIABLE PITCH

The performance of a straight blade VAWT can theoretically be greatly improved by causing - or allowing - the blades to pitch so as to avoid stall and maintain favourable angles of attack. The present paper extends the investigations of (2), (8) and (9) and compares the performance of three pitch control systems.

