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Review of aerodynamic developments on small horizontal axis wind turbine blade

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ABSTRACT

Wind energy is innately renewable, abundant in the earth and can possibly reduce the dependency on fossil fuels. Wind is an incarnation of sun and is always nourished by the latter. Approximately 10 million MW of energy can be continuously generated from the wind sources. In contrast to the large horizontal axis wind turbines (HAWT), which are established in the area with optimum wind conditions, small wind turbines are being installed to produce power irrespective of favourable wind conditions. Parameters associated with blade geometry optimization are important, because once optimized, shorter rotor blades could produce power comparable to larger and less optimized blades. A detailed review of various blade profiles and aerofoil geometry optimization processes to achieve high power coefficient in small wind turbines that falls below Reynolds number 500,000 have been presented in this paper.

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1. Introduction

Energy is the most considerable constituent of the socio-economic development and economic growth. Rapid rise in the level of greenhouse gases in the atmosphere, gradual increase in the cost of the fossil fuels and shortage of basins are the present major problems in the world that has created the awareness among the people to seek renewable energy [1]. The differential heating of the earth's surface produces wind by the sun. A rough statistical estimation has been given that with the available wind energy as much as 10 million MW of power could be generated. It is clean, eco-friendly and prime national security at a time when the decreasing global reserves of fossil fuels is an eminent danger in the sustainability of global economy. Large scale wind turbines are normally located at high potential wind resource areas, which are scarce in number. For areas of low wind potential, low cost, simple, portable, low noise and maintenance free structured small

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Nomenclature

ϕ	inflow angle (rad)
C_L	lift coefficient (dimensionless)
C_D	drag coefficient (dimensionless)
α	angle of attack (rad)
λ	tip speed ratio (dimensionless)
λ_r	local speed ration at any station r (dimensionless)
a	axial flow induction factor (dimensionless)
a'	tangential flow induction factor (dimensionless)
U_C	starting cut-in wind speed (m/s)
T_R	resistive torque (N m)
N_B	number of blades
ρ	air density (kg/m^3)
R	rotor radius (m)
I_{cp}	chord pitch integral
θ_P	pitch angle (rad)
c	airfoil chord or blade chord (m)
r	radial distance (m)
F	tip loss factor (dimensionless)
V_o	free stream wind velocity at hub (m/s)
D	overall rotor diameter (m)
d	local diameter (m)
α_t	angle of attack at tip of the blade (rad)
α_0	angle of attack at zero lift (rad)
k	acceleration factor
L_P	sound pressure level (dBA)
ω	rotor speed
σ	blade solidity ratio (dimensionless)
M	distance from the turbine to measurement point.
η_{Aero}	aerodynamic efficiency
θ_t	blade pitch angle at tip (rad)

wind turbines are of crucial influence in the rural and urban areas wind power extraction [2]. The approximate power coefficient of small scale and large scale wind turbines are 0.25 and 0.45, respectively. However, the earlier scientific community conducted most of the investigations with a focus more on structural analysis than on aerodynamic optimization but slowly the scientists are moving towards the aerodynamic analysis of wind turbines [3].

In the mid of 1980s, National Renewable Energy Laboratory (NREL) started to develop several families of aerofoils especially for wind turbine blades, and in the later years such development is continued by Delft University. The aerofoils having good performance characteristics in the fluid flow with the Reynolds number of range of 5×10^5 are the best for small scale wind turbines and their aerodynamic characteristics are listed in literatures [4–6].

Small scale wind turbines are classified based on their operating parameters and applications [7]. Improvement on aerodynamic performance and optimization of the turbine blades are widely based on Blade Element Momentum (BEM) theory, Genetic Algorithms and xfoil. The implementation of the above mentioned techniques on the blade design has produced dramatic developments in the small wind turbine sector. This paper reviews the recent developments in the aerodynamic profiles, starting characteristics, aerodynamic noise reduction and efficiency improvements of the small horizontal axis wind turbine blade.

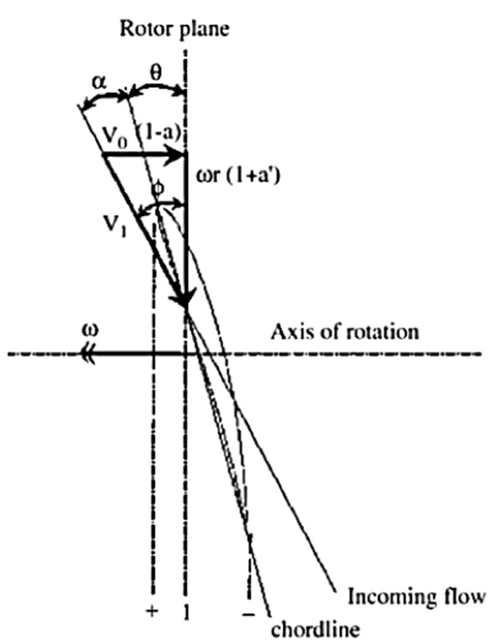

Fig. 1. Velocity diagram at radial station [11].

Table 2
Performance parameters for the airfoils considered for free and fixed transition at Re=300, 000. [5].

Airfoil	Free transition			Fixed transition			Percentage difference	
	$(C_l/C_d)_{max}$	C_L	C_{Lmax}	$(C_l/C_d)_{max}$	C_l	C_{lmax}	$(C_l/C_d)_{max}$	C_{lmax}
A18	79.6	0.80	1.23	41.2	1.03	1.22	48.2	0.7
BW-3	69.6	1.05	1.44	39.6	0.89	1.24	43.1	1.9
Clark-Y	77.2	0.85	1.35	39.1	0.83	1.13	49.4	16.5
E387	81.7	0.93	1.29	–	–	–	–	–
Go471a	82.3	1.08	1.40	–	–	–	–	–
NACA2414	66.6	0.90	1.23	–	–	–	–	–
RG15	69.0	0.66	1.14	–	–	–	–	–
S822	69.4	0.88	1.22	32.9	0.68	1.18	52.6	3.8
S823	62.7	1.05	1.18	30.2	0.78	1.14	51.8	3.0
S6062	73.1	0.65	1.11	–	–	–	–	–
S7012	72.1	0.71	1.14	40.4	0.94	1.15	44.0	-0.7
SD6060	73.5	0.72	1.11	–	–	–	–	–
SD7032	83.4	1.00	1.39	–	–	–	–	–
SD7037	76.3	0.84	1.28	44.1	0.99	1.32	42.2	-3.1
SD7062	77.5	1.23	1.66	45.1	0.96	1.23	41.8	25.8

Table 1
Operating parameters of small wind turbines [7].

Category	*W* (kW)	*R* (m)	Maximum rotor speed (rpm)	Typical uses	Generator type (s)
Micro	1	1.5	700	Electric fences, yachts	Permanent magnet (PM)
Mid-range	5	2.5	400	Remote houses	PM or induction
Mini	20+	5	200	Mini grids, remote communities	PM or induction