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A Review on Optimization of Windmill Rotor Blades to Operate with Improved Efficiency in Critical Wind Speed

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Abstract :- The main objective of the work is to increase the reliability of wind turbine blades through the blade angle orientation and also to increase the efficiency and running period of the wind turbine blades in Slight Extreme Climatic Conditions. The blade plays a vulnerable role, because it is the most important part of the energy production system. The material of the blade is to be wisely composed so has to posses the least weight and maximum strength. The design of the blade is to be carefully performed to enable in absorbing energy with its greatest efficiency which also accounts for the Energy saving methods. The application of specially designed lower airfoil has the ability to start at minimum wind speeds by providing initial torque and gathers speed as it increases work done per unit angle twist. Given that the importance of this work is the design of air blades and winglets, the blade design will be based upon the findings of this real time work. Computational gas dynamics plays a major role while determining the fluid flow over the wind blades and causing the blades to rotate, this also accounts in the intensity of revolution per minute.

Keywords: *Wind Turbine Rotor Blades, Airfoil, Fluid Dynamics, Winglet ,Gas Dynamics.*

I. INTRODUCTION

THIS paper discuss the improvement in design of an electricity-generating wind turbine blade in a way that produces maximum power output in expected all sorts of wind conditions.

This includes aero structures, and control structures. Considering a high range of input velocity of the wind that the maximum possible operating parameters and conditions of the turbine blade, and also by calculating the expected power output and extreme maximum structural load.

The Generator is modeled as to resist torque and a constraint during the maximum torque when it is allowed, and designing to keep the blades at the optimal pitch angle for a given input wind speed. We do not consider tower design, nor do we consider nacelle shape. Assumption is made so as no wind is input within 20% of the blade end radius. To constrain the design space and working area, Assumption of a three-bladed design in the design of experiments (DOE) test comparison showed that 3 blades was highly efficient compared to both 4 and 5-bladed designs in most of the cases. Even though the modern blades are generally being constructed with composites and alloys, our knowledge of structural behavior and structural designs in composites and alloys is limited, and we therefore elected to assume that our wind turbine has a control system and that allows it to feather and float the blades in a manner that the structural stresses and strains are alleviated when the input wind velocity is very high.

II. DESIGN VECTOR

In order to perform numerical calculations and optimization, the design must be split or broken down into a list of decision variables, constrains and parameters that completely define the core design. The minimal number of design variables is accounted to define the blade shape but then is mapped to the design vector into a high dimensional discretization for analysis.The bounds were to be chosen to mirror the physical constraints of the wind turbine blade design. For example, the blade radius is limited to 16.15 m and also, the sum of the bounds for the angle of twist and pitch control angles is ranged from unity to 90Degrees. This confirms a realistic range of accessible geometric blade angles. The design vectors and bounds are shown in Table 1. In addition, to it,a group of fixed design parameters such as the number of turbine blades, are defined in Table 2.

For the distribution of twist, the twist at the turbine hub is assumed to be 0, so only two decision variables for the value of twist angle at the midpoint and end of the blade specify the entire distribution. Similarly, the foil shape parameter specifies a linear combination of 2 airfoil shapes and characteristics. The foil at the root is the S814 foil, and foil at the tip is the S813 foil. The value of the foil shape is considered to be 0 at the root and one at the tip, and therefore, only a single decision variable is needed to specify the parameter at the midpoint. Both the chord and control curve distributions are specified by 3 points. Also noted that the angles are specified in radians in our codes, but are displayed in degrees in figures for convenience.

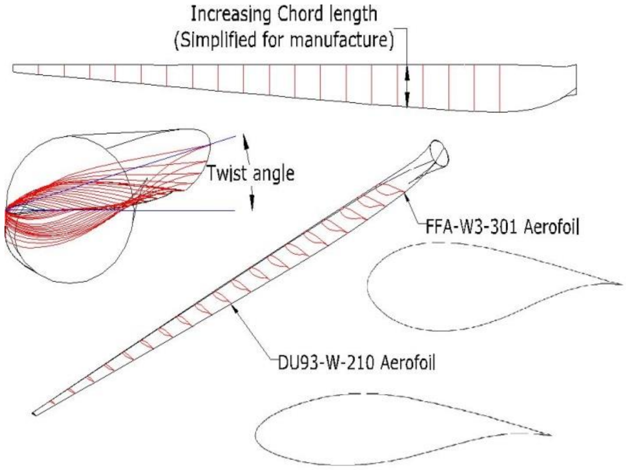


Figure 1. A modern HAWT blade with multiple aerofoil profiles, linear chord length increase.

III. BLADE SHAPE SUMMARY

A efficient rotor blade consist of several aerofoil profile blended at an angle of twist terminating at a circular flange similar to modem HAWT blade as shown in Figure 1 . It may also include tip geometries for reducing loss.

- Reduction the angle of twist.
- Linearization of the dimensions of chord width.
- Reduction in the number of differing aerofoil profiles.

All simplifications are detrimental to rotor blade efficiency and should be justified. The introduction of new moulding techniques and materials has to be allowed by the manufacture of increased complex blade shapes. However, the economics of production couples with difficulty of design analysis still dictate final geometry of the blade design. Leading wind turbine producers now include most optimization features as angle of twist, variable chord length and multiple aerofoil geometries.

IV. OBJECTIVE

The performance or the efficiency of the turbine can be measured as the cost of producing a unit amount of power based on the RPM, or inversely, the power output obtained by a given initial cost. We chose to measure the efficiency of the turbine as the expected power output over a set of incoming wind speed given by a Weibull distribution with site-specific shape coefficients divided by the total volume of material required to construct the turbine blades.

Objective = J(x, param) = Expected Power Output is also equal to PE (x, param) ,(1)Blade Material Volume Vblades(x, param)

where x is the actual turbine design vector as defined in Table 1, param is a set of fixed parameters as defined in Table 2, PE is the expected power in the unit of Watts, and Vertical blades is the combined material volume of all blades in m3 . Both, x and param completely define a wind turbine design and all the constant parameters needed to derive the expected power output, blade volume, and actual blade structural stresses.

Table 1: Decision Variables

Decision variable	**Symb -ol**	**Dimen -sion**	**Lower band.**	**Upper band**	**Units**
Blade radius	R	1	5.00	16.15	m
Chord length distribution	C	3	0.1	10	m
Maximum generator torque	Qmax	1	1000	20000	Nm
Blade shell thickness	t	1	0.004	0.020	m
Maximum design wind speed	k	1	0	4	std. dev. above mean
Twist distribution	T	2	0	π/4	radians
Foil shape distribution	F	1	0	1	non-dimensional
Pitch control curve	β	3	0	π/4	radians

Table 2: Selected Design Parameters

Parameter	**Symbol**	**Value**	**Units**
Blade material yield strength	σY	20	MPa
Weibull distribution scale parameter	cweibull	5	-
Weibull distribution shape parameter	Kweibull	2.19	-
Blade discretization in Points	N	10-11	-
Number of wind speeds in Weibull integration	nW	7	No.

V. CONSTRAINTS

In order to make the codes as general as possible, and to also to use with heuristic algorithms, we studied and modeled our structural stress constraints in terms of penalty function as opposed to including them explicitly. While logarithmic barriers and functions are extremely attractive in terms of convergence properties by convition, they are typically more useful for convex feasible sets, and it is very important to change the barrier coefficient at the correct rate and hence, the solution converges quickly and does not becomes infeasible. Since we have little intuition and knowledge to predict when and how the actual structural stresses will exceed their limits and the feasible space is likely to be non-convex, we elected instead to employ a square-term penalty functions of where (x, param) is the penalty function of a particular design, (arg)+ defins max(arg, 0), penalty is defined as the penalty coefficient applied to each blade stress violation, σ maxris the maximum stress in MPa at a particular blade section over all operating wind velocities, and σ allowable is a partial fraction of the yield stress at 70%. Because the stress violations are all in the same units. Note that when σ maximum stress < σ allowable for all blade radii, ξ(x, param) = 0. For aluminum with σY = 20 MPa, σ allowable = 70% × 20 MPa = 14 MPa.

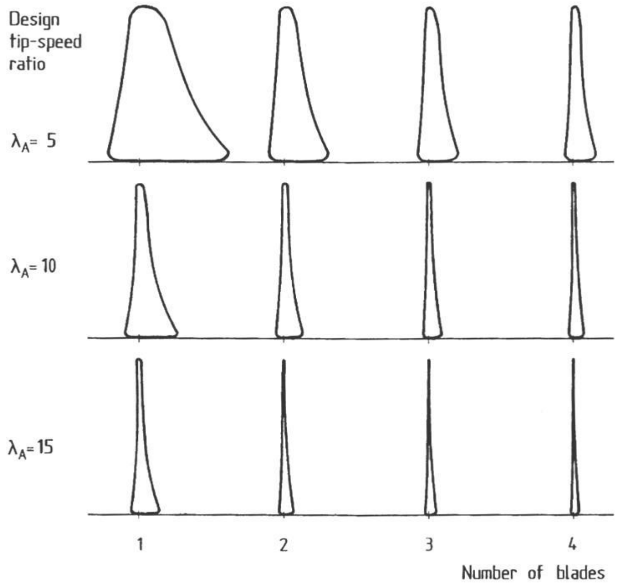


Figure 2. Design tip speed ratios and number of blades.

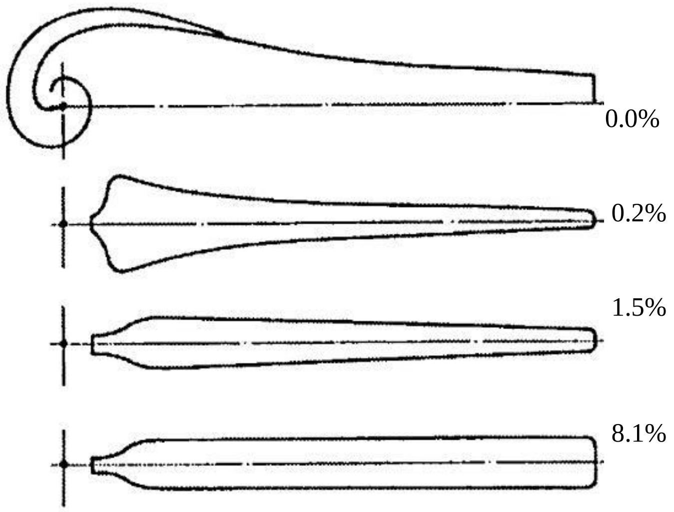


Figure 3. Efficiency loss as a result of simplification to ideal chord length .

The form of a HAWT rotor blade is defined by using the BEM method by calculating the total chord length according to Betz limit, local wind speeds and velocities with anemometer and aerofoil lift. Several theories persist for calculating the optimum chord length which range in complexity as [1,4,10,12], with the most simplest theory based on the Betz precesion. For the blades with tip speed ratios of 6 to 9 using aerofoil sections with negligible tip losses and drags , Betz's theory of momentum gives a good approximation. In inputs of low tip speeds, high drag in aerofoil section and rotor blade sections around the rotor blade hub, but this method could be considered lesser or inaccurate. In these cases, drag and wake losses should be accounted for [4,12]. Betz method is the origin of basic structure of the modern wind turbine blade as shown in Figure 2. However, in practice generally, advanced methods of optimization techniques are used.

$$C_{opt} \quad \frac{2r}{n}\,\frac{8}{9C_L}\,\frac{U_{wd}}{V} \qquad \text{where } V_r \sqrt{V_w^2 \quad U^2}$$

U wind speed (m/s)
U_{wd} Design windspeed (m/s)
C_{opt} Optimum chord length
r radius (m)
n Blade quantity
CL Lift coefficient
Vr Local resultant air velocity (m/s)

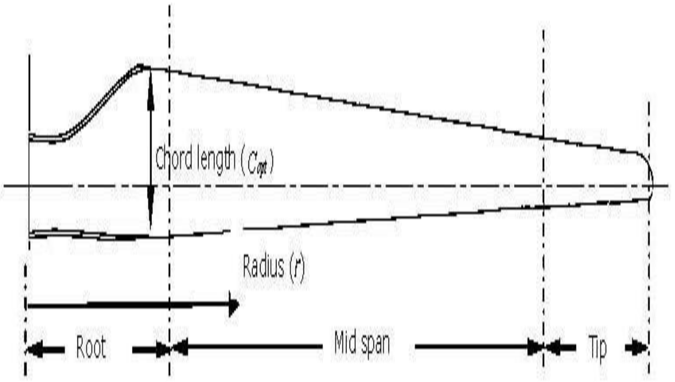
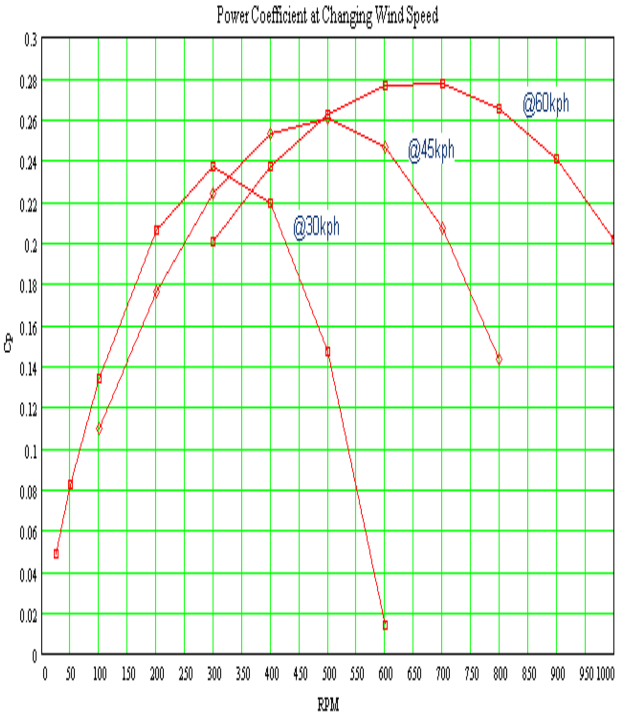


Figure 4. Design tip speed ratios and number of blades.

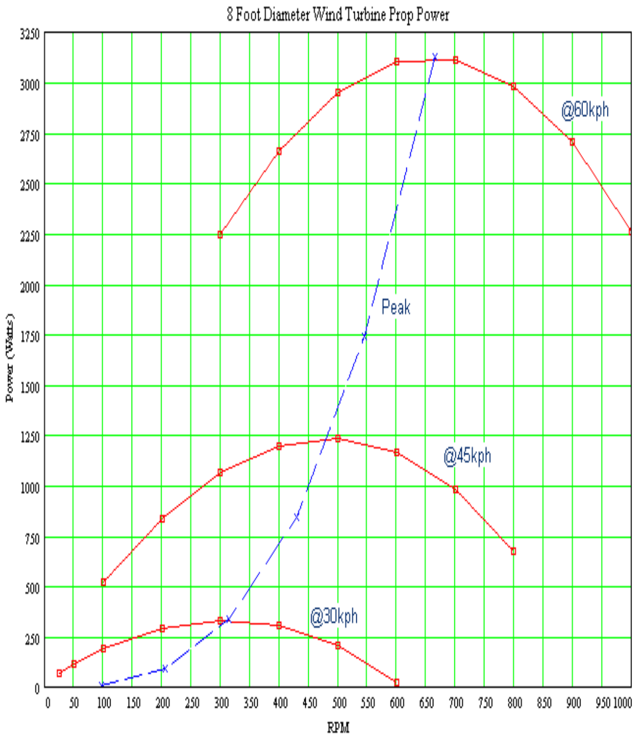
Assuming that a reasonable lift coefficient is to be maintained, utilising a blade's optimization method that produces blade plans principally depends on the tip of blade design structure, velocity ratio and total number of blades as in Figure 2. Low tip speed ratios produces a rotor with a high ratio of solidity, which is the ratio of blade's area to the area of the total swept rotor. It is very useful to reduce the area of solidity as it accounts to a decrease in material usage and therefore production costs.

Generally, in practice the total chord length is simplified to facilitate manufacturing and which involves some extension of the increasing chord length as shown in Figure 4.

For optimum chord dimensioning (Equation 1) the quantity of blades is to be considered negligible in terms of efficiency. Whereas in practice when blade losses are to be considered, a 3% loss is incurred for two bladed designs and a 7% to13% losses for accounted 1 bladed design when compared to 3 blades. A 4 bladed design is inferred to offer marginal efficiency that increases which do not justify the production cost of a extra blade. Tower loading must also to be considered while choosing the appropriate blade quantity. 4,3,2 and 1 bladed designs lead to increased dynamic loads.



Graph 1: Power Coefficient at changing wind speed



Graph 2: Power Vs. Rpm

The imposing size and location of wind turbine blades signify that the visual impact must also be considered. 3 bladed designs are said to appear smoother during rotation and hence more aesthetically pleasing. Faster 1&2 bladed designs have an apparent vibratory motion . Three bladed rotors are also thought to appear more ordered at the stationary position.
An inter-module optimization is performed by the Control module, which chooses the optimum angular speed ω at a given point by calling the Aero module successively and performing a line of search. The global optimization is performed and is called as the Wrapper module, and the Aero module performs its own root-finding technique to near précising the wind velocity at the turbine disk.

VI. WRAPPER MODULE

The design takes as input, the design vector and parameters and output, the nearly expected power, total blade material volume, and maximum structural stress, thereby serves as the wrapper for the entire function evaluation. It translates the decision variables representing distributions into splines, which it then passes at a given number of specified points, in the blade for analysis.

As it is documented in the literature, wind profiles and blade designs are commonly approximated nearly by Weibull distributions. The Expected Power module discrete the control curve spline, β,and also evaluates the performance of the turbine at each input wind speed as called the Control module, and Simpsons Rule integrated over the Weibull distribution on the turbine blade power output in order to derive the expected value. The Structures module to finds the extreme stress value in each blade section over all input wind speeds.

VII. CONTROL MODULE

The Control module optimizes the total power output of a set of blade geometry decision variables and a given controlled pitch angle by selecting the optimal rotational speed without violating or disturbing the maximum allowable torque, Qmax, constraint on the working generator. The algorithm also assumes a concave power curve with respect to the rotational speed, ω, and finds the point of maximum power by f minimum band routine. If the operating point exceeds Qmax, the rotational speed is incrementally raised until the operating torque matches Qmax by employing f0 routine.

VIII. AERO MODULE

The Aero module calculates the turbine torque and power for a given rotational speed, control pitch angle, and blade geometry details by iteratively solving for the velocity behind the blade based on the momentum taken out of the blade at the turbine disk. Forces at the turbine disk are calculated by integrating lift and drag, calculated by lookup table from the airfoil property curves, over the blade radius. The iteration is enhanced by a relaxation factor, which is iteratively lowered to counteract instability.

IX. STRUCTURE MODULE

The Structure module calculates the design and structural stresses based on the aerodynamic loading and rotational speed per minute of the blade. The airfoil is replaced with an equivalent rectangle with the same total area and chord length dimension as the airfoil, and the whole blade is treated as a cantilevered beam. Aerodynamic loads acts at the quarter chord point at each station and is transferred to the center of the rectangular shell with moments. Bending moments, the centripetal force due to the rotation of the rotor beam cause normal stresses, which are added with shear stresses to calculate the max stress in the blade section. The shell thickness at each station is the decision variable, t The spar box thickness is optimized at the range of 5 to 20% of the breadth of the box and in order to minimize cross-sectional area without exceeding the total maximum allowable stress. If the thickness is tight at 20% at any section, the maximum allowable stress is violated and disturbed at that section.

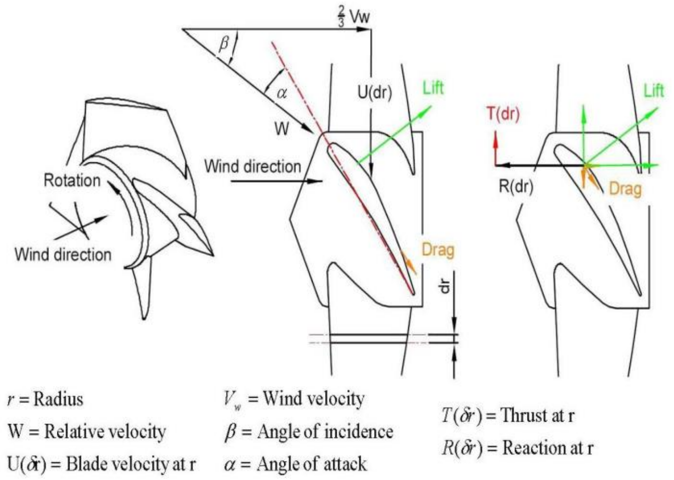


Figure5: Aerodynamic Force as a constraint at blade end

Dynamic and Aerodynamic loads are produced by lift and drag of the blades aerofoil section as in Figure 5, which is dependent on wind velocity VW, rotor blade velocity U, surface finish of the blade and angle of attack (α) . The angle of attack is dependent on blade twist, degree of turn and pitch.

X. OPTIMIZATION

We performed a design space exploration by studying the generation of space-filling Design of Experiments DOE using the orthogonal array. We chose factors and levels as presented in Table 1 and Figure 2. The selection of factors and levels were derived from extensive point-testing of our analysis and reviews of research journals. For eg, the level of Factor 1, corresponding to blade radius, were chose to fill only the upper portion of the range for the blade radius as a larger radius increases the overall amount of wind energy entering the turbine disk blades. For other factors that represent distributions, distribution shapes, or relative magnitudes. At least one level in each factor was chosen to correspond with optimal decision variables from a gradient related optimization we performed early in our Review.

XI. CONCLUSION

The formulation has both nonlinear, non-convex objective function and nonlinear, non-convex feasible region. However, Function evaluations are non-trivial and can range from few seconds to ten minutes, depending on the criteria of design vector. However, employing only continuous decision variables, and believing both the objective and constraints are smooth functions. Because of the multiple local optima and expensive function evaluations, our analysis lends itself to design space exploration and the use of multi-start gradient methods. Where algorithms that can work well to find global optima, they are typically very expensive to run, and in practice we review that we never had enough computational resources to fully converge with heuristic methods including genetic algorithms and simulated annealing techniques.

This Review will account as a potential asset in understanding the turning torque per unit angle of twist of a rotor blade in a windmill and also the enhancing the efficiency to operate at variable and critical wind speed.

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