# Optimization of Wind Turbine Blades Using Genetic Algorithm

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Abstract -This paper presents a design tool for optimizing wind turbine blades. The work considers optimizing the blade of wind turbines with respect to maximizing the energy yield of a wind turbine. The design variables are the shape parameters comprising the chord, the twist and the relative thickness of the blade. Genetic algorithm was used to illustrate the optimization technique; two wind turbines of different sizes are subjected to analysis. The results obtained are in good agreement with other published results.

*Key words*: Optimization of blades; energy cost; wind turbine design; Genetic Algorithm

## I. INTRODUCTION

 $\mathbf{F}^{\text{or wind energy to become competitive with respect to}$ be to reduce the cost of energy from wind power. In modern wind power researches, how to minimize the cost of a wind turbine per unit of energy is an important task. The shape of the rotor blades plays a decisive role in determining the overall aerodynamic performance of a horizontal axis wind turbine (Fuglsang and others, 1995; Giguere and others, 1999; Benini and others, 2002). Thus, aerodynamic optimization of the blade shape is a very important stage in the design and manufacturing of wind turbines. In earlier days, the Glauert and Wilson methods were mostly used for blade design (Spera, 1994). The objectives of these methods were to obtain the maximum power coefficient of each blade section at the design wind speed. Because the time variation characteristics of wind speed are not taken into account, blades designed by these methods cannot achieve the maximum annual energy output. Furthermore, design results from these methods must be substantially corrected to get smooth chord length and twist distributions (Spera, 1994). Because the corrected results already deviate from the design points, effectively controlling design results poses problems. Conventional search algorithms, such as the feasible direction method and the complex method, are often prone to converging on the local optimal point (Gen and others, 1999). For some complicated problems, it is difficult to obtain a global optimal result and user interference must be carried out. For example, changing the

About- Department of Mechanical Engineering, Faculty of Engineering, University of Port Harcourt, Port Harcourt, Nigeria. e-mail: onyewudialajulius@yahoo.com Tel. +2348037316672 ; +2348063314201 design parameters or shifting the initial feasible domain to execute multiple search processes is needed to get the best local optimal result as the global optimal one. This prevents the designer from concentrating on the problem itself and guaranteeing that the designed result is globally optimal. Several researches have been carried out on the viability of the wind turbine for power generation. These researches cover the entire design of a wind turbine from the blade design to the intricate control systems which allow for optimum performance. On the note-able work on the theory of wind machines, using Betz equation shows a mathematical approach for evaluating various parameters involved in the design of the wind turbine (Ragheb, 2008). Philip, (2004), research covered wind resources, the Origin of the wind. He showed how to estimate available wind power and how a horizontal axis wind turbine (HAWT) works. Through the use of relevant equations, he obtained the power coefficient using the Betz relation. Other aspects covered by his research which are essential to the wind turbine technology are the aerofoil concept, Blade Element-Momentum theory, brakes, gearbox, generators and aesthetic considerations. There are a number of recently published papers dealing with the optimization of wind turbines. Fuglsang and others, (1999), develop optimization methods for wind turbine rotors. Stiesdal, (1999), developed the wind turbine, components and operation. Hansen, (2000), worked on aerodynamics of wind turbines. Fuglsang and others, (2001), developed site-specific design optimization of 1.5-2.0 MW wind turbine. Benini and others, (2002), developed optimal design of horizontal axis wind turbines using blade-element theory and evolutionary computation. Slootweg and others, (2003), worked on inside wind turbines, fixed versus variable speed. Grauers, (2003), worked on efficiency of three wind energy generator systems. Jureczko and others, (2005), developed optimization of wind turbine blades. In an attempt to achieve optimization and power analysis of a wind turbine, Afolami, (2007), improved the operation of a wind turbine through replacement of some components of the wind turbine in other to collect data over a period of time thereby analyzing the amount of power generated within a given wind direction, speed and location. The data obtained from the power analyses was compared with that obtained from the wind data logger. Michael, (2007), showed that modern wind turbines have become an economically competitive form of clean and renewable power generation. Optimizing wind turbines for specific sites can further increase their economic competitiveness. In his study, he carried out an economic optimization analysis of a variable speed, three

blade, and horizontal-axis wind turbine. This work presents design tool for optimizing wind turbine blades. This considers optimizing the blade of wind turbines with respect to maximizing the energy yield of a wind turbine. To achieve the optimization in this work, the genetic algorithm code in MATLAB is written for the turbines and this code can be used for any type of wind turbine provided that the objective function is the same.

## II. PROBLEM FORMULATION AND SOLUTION

As the costs from operation and maintenance often can be accounted as a small percentage of the capital cost, the reduction of the capital cost becomes an essential task for designing wind turbines. Moreover, a well designed wind turbine with a low cost of energy always has an aerodynamically efficient rotor. Therefore, the rotor design plays an important role for the whole design procedure of a wind turbine. In the current study, the objective function is restricted to the cost from the rotor. Thus the objective function is defined as

$$Minimize \ Z = \frac{C_{rotor}}{AEP} \tag{1}$$

where Z is the cost of energy of a wind turbine rotor;  $C_{rotor}$  is the total cost for producing, transporting and erecting a wind turbine rotor and AEP is annual energy production. Therefore the total cost of a rotor,  $C_{rotor}$ , is a relative value defined as (Wang and others, 2009).

$$C_{rotor} = b_{rotor} + (1 - b_{rotor})W_{rotor}$$
(2)

where  $W_{rotor}$  is the weight parameter of the rotor. The fixed part of the cost for a wind turbine rotor  $b_{rotor}$  is chosen to be 0.1 (Wang and others, 2009). In this work, the weight parameter is calculated from the chord and mass distributions of the blades. Supposing that a blade can be divided into *n* cross-sections,  $W_{rotor}$  is estimated as

$$W_{\text{rotor}} = \sum_{i=1}^{n} \frac{m_i C_{i,\text{opt}}}{M_{\text{tot}} C_{i,\text{or}}}$$
(3)

where  $m_i$  is the mass of the i - th cross – section of the blade;  $C_{i,opt}$  is the averaged chord of the i - th cross section of the optimized blade;  $C_{i,or}$  is the averaged chord of the i - th cross section of the original blade;  $M_{tot}$  is the total mass of the blade. The power curve is determined from the Blade Element Momentum (BEM) method (Hansen, 2000). In order to compute the annual energy production (AEP), it is necessary to combine the power curve with the probability density of a wind (i.e. the Weibull distribution). The function defining the probability density can be written in the following form:

$$f(V_i < V < V_{i+1}) \exp\left(-\left(\frac{V_i}{A}\right)^{\kappa}\right) - \exp\left(-\left(\frac{V_{i+1}}{A}\right)^{\kappa}\right)$$
(4)

where A[-] is the scale parameter, K[-] is the shape factor and V[m/s] is the wind speed. Hence the shape factor is chosen to be K = 2 corresponding to the Rayleigh distribution. If a wind turbine operates about 8760 hours per year, its AEP can be evaluated as (Wang and others, 2009).

AEP 
$$\sum_{i=1}^{N-1} \frac{1}{2} (P(V_{i+1}) + P(V_i)) \cdot f(V_i < V V_{i+1}) \cdot 8760$$
 (5)  
or

$$AEP = \sum_{i=1}^{N-1} \frac{1}{2} \left( P(V_{i+1}) P(V_i) \right) \cdot exp\left( -\left(\frac{V_i}{A}\right)^k \right) exp\left( -\left(\frac{V_{i+1}}{A}\right)^k \right) \cdot 8760$$
(6)

where  $P(V_i)$  is the power at the wind speed of  $V_i$ . The expression for power *P* is given by

$$P = \frac{1}{2}\dot{m}V_0^2 = \frac{1}{2}\rho A_0 V_0^3$$
(7)

where  $\dot{m}[m^3/s]$  is the mass flow rate;  $V_0[m/s]$  is the wind speed;  $\rho[kg/m^3]$  is the density of the air; and  $A_0[m^2]$  is the area of the wind speed.





To obtain a reliable optimization of a wind turbine blade, the geometry of the blade needs to be represented as much as possible. This requires a great number of design variables. On the other hand, the selection of more design variables in the optimization procedure requires more complex solution algorithm and computational time. The design variables are often chosen to be the parameters controlling the rotor shape, airfoil characteristics, rotational speed and pitch angle. The rotor shape is controlled by the rotor diameter, chord, twist, relative thickness and shell thickness. The airfoil characteristics are the lift and drag dependency on the angle of attack. Based on a general chord distribution, a cubic polynomial is used to control the chord distribution. Because of the multiple distribution characteristics, a spline function is used to control the distributions of twist angle and relative thickness. The constraints of the design variables are

$$X_{i \min} \le X_i \le X_{i \max} \quad i = 1, 2, 3$$
 (8)

where  $X_{i \min}$  is the lower limit and  $X_{i \max}$  is the upper limit for chord, twist angle and relative thickness of the blade respectively. As a usual procedure for optimization problems, we have one objective function and multiple constraints. To achieve the optimization, the genetic algorithm code in MATLAB is written for the turbines and this code can be used for any type of wind turbine provided that the objective function is the same.

#### III. RESULTS AND DISCUSSION

As a first consideration of the optimization, the Mexico 25kW experimental rotor is chosen (Wang and others, 2009). Table 1 shows the input data.

Table 1 Input data for Mexico 25kW experimental rotor and Tjaereborg 2MW wind turbine rotor.

Parameter	Units	Mexico 25kW	Tjaereborg 2MW wind
		experimental rotor	turbine rotor
Number of blade	_	3	3
Air density	$kg/m^3$	1.19	1.19
Radius of the rotor	т	2.25	30.56
Total mass of the blade	kg	4.62	9321.7
Lower limit for chord	m	0	0
Lower limit for twist	0	0	0
Lower limit for relative	%	18	12.2
thickness of the blade			
Upper limit for chord	m	0.24	3.3
Upper limit for twist	0	20	8
Upper limit for relative	%	100	100
thickness of the blade			
Scale parameter	_	6.8	6.8
Shape factor	_	2	2
Power coefficient	_	0.59	0.59
Coefficient of lift	_	0.7	0.7
Fixed part of the cost	_	0.1	0.1
for a wind turbine rotor			
Tip speed ratio	—	4	4
Angle of attack	0	5	5
Wind Speed	m/s	16	2

From Figure 2, it can be seen that the chord keeps closely to the original distribution for most of the blade except that it narrows down significantly near the blade tip. The reason for this is that this section of the blade does not contribute much to the power and thus is not required to have a thick chord. The relative thickness distribution does not change during the present optimization. The AEP of the optimized rotor is reduced by about 0.8%, whereas the cost of the optimized rotor comes down by approximately 1.9%. Thus the cost of energy for the Mexico rotor can be reduced by approximately 1.15%. However from the trend and pattern of the graphs in Figures 2 and 3, it is seen that genetic algorithm is in line with other published results.

As a second test case of the optimization techniques, the Tjaereborg 2MW rotor is chosen (Wang and others, 2009). In Figures 4 and 5, the chord and twist angle distributions of the optimized Tjaereborg rotors are shown. From Figure 4, it is seen that the optimized blade has a much smaller value of chord in the region between 10 m and 23 m. From the position at a radius of 23 m to the position at a radius of 28 m of the blade, the chord keeps the original distribution. This is because the axial and tangential forces on this part of the blade contribute significantly to the power. Again the chord reduces significantly in the region near the tip. The change in the twist angle is not very significant because of the constraint on the maximal thrust from which a bigger thrust would shorten the blade life and increase the cost.



Figure 2: The chord distribution of the optimized rotor using genetic algorithm

The AEP of the optimized rotor is reduced by about 4% whereas the cost of the optimized rotor comes down by approximately 7.1%. Thus the cost of energy for the  $T^{J}$ aerebor<sup>g</sup> rotor can be reduced b<sup>y</sup> approximate<sup>ly</sup> 3.4%.

0.5

0.2 0

Ο

However from the trend and pattern of the graphs in figures 4 and 5, it is seen that genetic algorithm is in line with other published results.

2

2.5



radius(m)

1.5





Figure 5: The twist angle distribution of the optimized Tjaereborg 2MW rotors using genetic algorithm.

# IV. CONCLUSION

An optimization model for rotor blades of horizontal axis wind turbines that accounts for the minimum cost of energy which is defined as the ratio of the cost of rotor to the annual energy production is presented. To develop a generalized optimization program, genetic algorithm is used as the search algorithm. Utilizing the developed program, two different blades of 25KW and 2MW wind turbine are optimized. The results obtained are in good agreement with other published results.

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