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Optimization Design of Wind Turbine Blade based on MATLAB

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Abstract

The author to Willson wind turbine blade optimization design mathematical model, draw the corresponding program block diagram, and use MATLAB high-level programming language to write the wind turbine blade aerodynamic design program. Application of the design program design, the manufacture of the small wind turbine model, and through the actual vehicle test on the pneumatic performance. Experiment proves that the application of MATLAB high-level programming language design of wind turbine blade to realize the maximization of wind energy use efficiency; Matching with spring type variable propeller torque mechanism, but also realized the author predicted low wind speed large output, high wind speed steady output of the ideal effect, in order to solve the low wind speed wind turbine start-up, big wind speed under the condition of the wind turbine output is too large under the condition of the problem of difficult to control provides a new train of thought.

Keywords: *MATLAB optimization design of wind machine*

1. Introduction

Wind is called green energy, which is renewable and pollution-free and inexhaustible [1]. The use of wind energy includes a variety of technology, generate electricity, heating and navigational *etc.*, [2]. People pay more and more attention to the wind power generation technology, because it has the advantages that not better than other ways. The wind turbine is a mechanical device which converts the wind energy into electric energy. The wind wheel is the main component of a wind generator, composed of blade and hub. The wind wheel performance is directly related to the operation of the whole unit. It is for long ages since people pay close attention to the issue that how to ensure the efficiency and stable operation of wind turbine. Efficient means not only easy to start to wind turbine in low wind speed conditions, but also maintain a high wind energy utilization rate in normal speed. Stable refers the wind conditions of wind turbine can effectively limit its output, in order to prevent equipment damage caused by excessive output. The aim is to cooperate with some scientific researches, we conduct research full of variable pitch wind energy conversion device [3]. In this thesis, the author used the programming language MATLAB, developed that wind turbine blade aerodynamic design software, design, and manufacture of wind turbine blades with high performance.

Usually, the design of the wind blade needs maximum wind energy, the maximum wind energy utilization efficiency [4]. It is belongs to the optimization design problem in engineering calculation, which has complicated calculation process and program nesting level range. The designer will face the arduous work of programming, if they make use of traditional computer languages. MATLAB is an advanced language, which is widely used in engineering calculation and the numerical analysis. Compared with the traditional computer languages, MATLAB has advantages of a power function, easy to use and the precision computation. Based on design method of Willson blade optimization [5]. The author put forward the optimization design method for high speed wind turbine blade in MATLAB.

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2. Optimized Design of Wind Turbine Blades

Design guidelines: Generally, we should consider the following two aspects for the design of wind turbine blade [6]: (a) the wind turbine wind energy wind turbine for higher energy utilization rate. (b) The torque characteristics of wind turbine meet the low wind speed easy starting and high wind speed operation. In practical design, the above two points are a pair of contradictions that restrict each other and need to consider both of them. It can effectively guarantee the torque characteristics of wind turbine though this topic development process variable pitch wind energy conversion device. Therefore, we do not consider the torque characteristics in the design of wind turbine blades and the revision of the blade, and will focus on improving the efficiency of pneumatic.

The mathematical model of Willson method Willson aerodynamic optimization design method is the comprehensive application of momentum theory, the momentum theory and blade element theory. The mathematical model of the method is as follows [7]:

$$dCp = \frac{8}{\lambda_0^2} b(1-a) F \lambda^3 d\lambda \tag{1—1}$$

$$b(b+1)\lambda^2 = a(1-aF) \tag{1—2}$$

$$\tan\phi = \frac{V_1(1-a)}{\Omega r(1+b)} = \frac{1}{\lambda}\cdot\frac{1-a}{1+b} \tag{1—3}$$

$$\frac{NCC_L}{r} = \frac{8\pi aF(1-aF)}{(1-a)^2}\cdot\frac{\sin^2\phi}{\cos\phi} \tag{1—4}$$

$$f = \frac{N}{2}\cdot\frac{R-r}{R\sin\phi} \tag{1—5}$$

$$F = \frac{2}{\pi}\arccos(e^{-f}) \tag{1—6}$$

Wind energy utilization coefficient CP of wind turbine blade is an important index to represent the blade performance [8]: The basic ideas of blade optimization design are as follows: Calculate the blade chord length and twist to all along the development of the angle targeted the maximum value for coefficient CP. The blade chord length and twist angle have direct relation to the axial interference coefficient (a) and tangential interference coefficient (b) and the leaf tip loss coefficient (f). Generally speaking, the maximum value for CP as the target, calculating a, B, F coefficients of the blade element, and finally determine the chord length and twist angle of the blade. Based on the blade element theory, CP and the leaf dCP are the maximum value.

Finally, the optimization design of blades is summarized into a conditional extreme values problem. As the objective function and constraint functions for the equations are follows (1-1) and (1-2). Calculate the various leaf element that meet the conditional extreme values problem, and work out axial interference coefficient (a) of each section and tangential interference coefficient (b) and the leaf tip loss coefficient (f).Using equation （1-3）～（1-6）and $\beta = \phi - \alpha$ to determine chord of each section.

1.2 The calculation program design of blade optimization in MATLAB

The main task of this subject is the calculation of wind turbine blade aerodynamic design. The calculation workload involved in very large. Manual calculation is clearly undesirable, which is no convenient and difficult to ensure accuracy of calculation. MATLAB language is a advanced language which is widely applied to engineering

calculation and the numerical analysis areas. The strong function is the traditional high-level languages incomparable [9]. For example, optimization problem solving a described above, using the traditional BASIC,FORTAN and other language, probably need dozens, even hundreds of lines of program statements, and MATALAB to solve the same problem require only a few lines of program can get accurate results. The reason is that the MATLAB language makes many typical mathematical problem to the preparation of a program module, as long as the call these module requirements specified [10]. It can be an easy job to solve the problem. This topic is selected the MATLAB language as a tool of calculation, the design calculation procedure is greatly simplified, and improve the accuracy.

1.2.1. Design and Calculation of Main Function Flow Chart: My blade optimization design program based on Willson method calculation steps are as follows:

Setp1. The leaves averaged into several micro blades along the leaf blade.

Setp2.For each element, combined with (1-5),(1-6),solving the optimization problem of the objective function for the (1-1) and conditional function for (1-2),so that each section value of a、b and F.

Setp3. calculate each blade chord C by (1-4)

Setp4. Calculation wind angle φ by (1-3), and determine the blade torsion angel β according to $\beta = \phi - \alpha$

Setp5. Linear correct to geometric parameters of the blade have been calculated.

Setp6. According to the airfoil manual, determine the section airfoil coordinates.

Design and calculation of main function flow chart shown in Figure 1. Firstly, input the original parameters of shape design. Secondly, calculate 40 section of the blade though a 40 steps cycle. Finally, the calculated results output to the specified file. In the cycle, author called the Fmincon function in MATLAB to solve optimization problem, also called the BOB (Re) function witch has been written for attack angle of each section

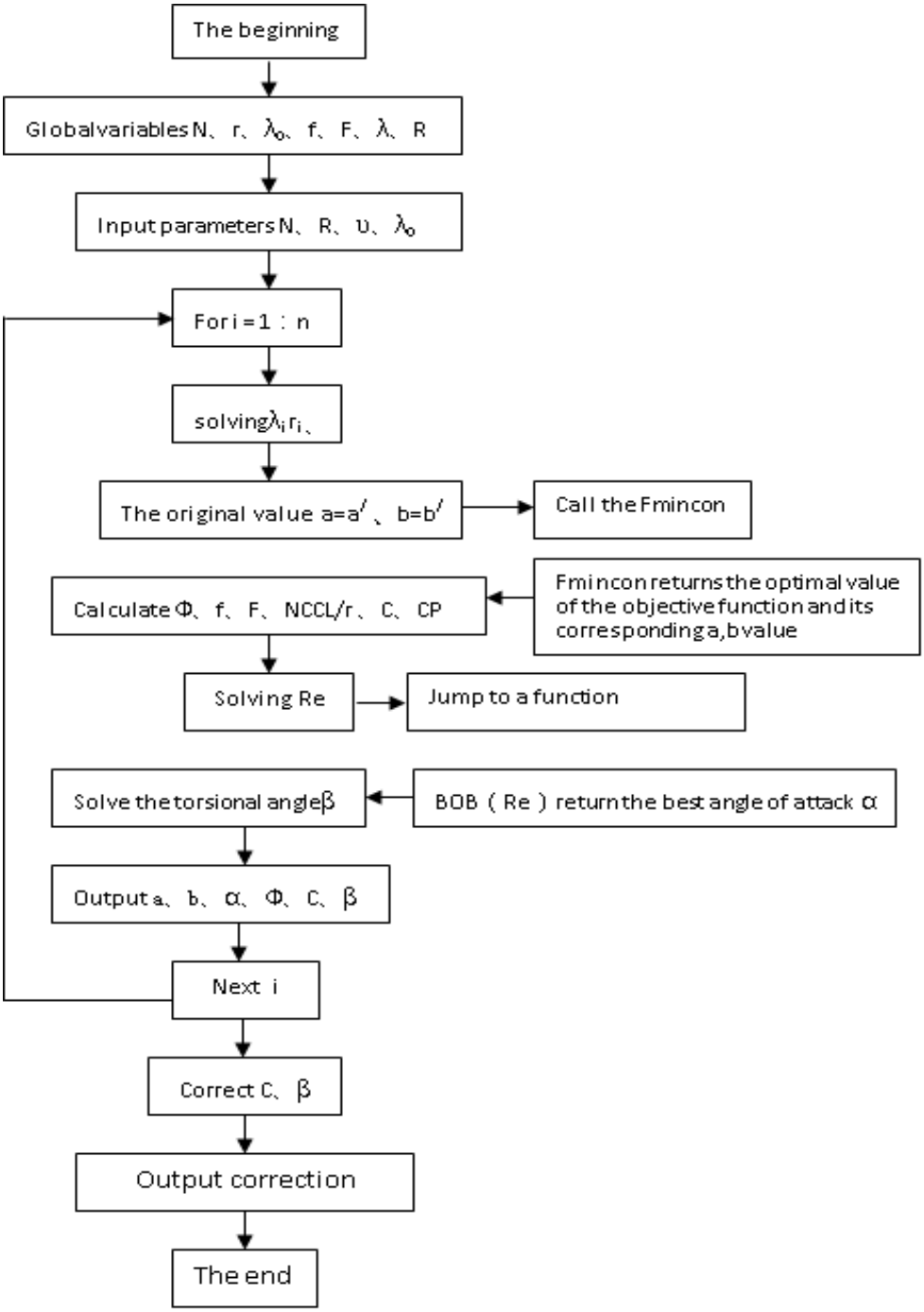

Figure 1. The Calculation Flow Chart Design

1.2.2. Design of the Sub Function: Considering the Reynolds number has a certain influence on the selection of airfoil data, the author designed a named BOB(Re) sub function in order to calculate attack angle of each section based on specific airfoil data. Re is the formal parameter, it can accept the actual parameters passed to the main function, and return to the main function of an attack angle value. Formal parameter Re plays the data transfer role in this process. The value is the best attack angle of blade each section, the whole process is shown in Figure 2.

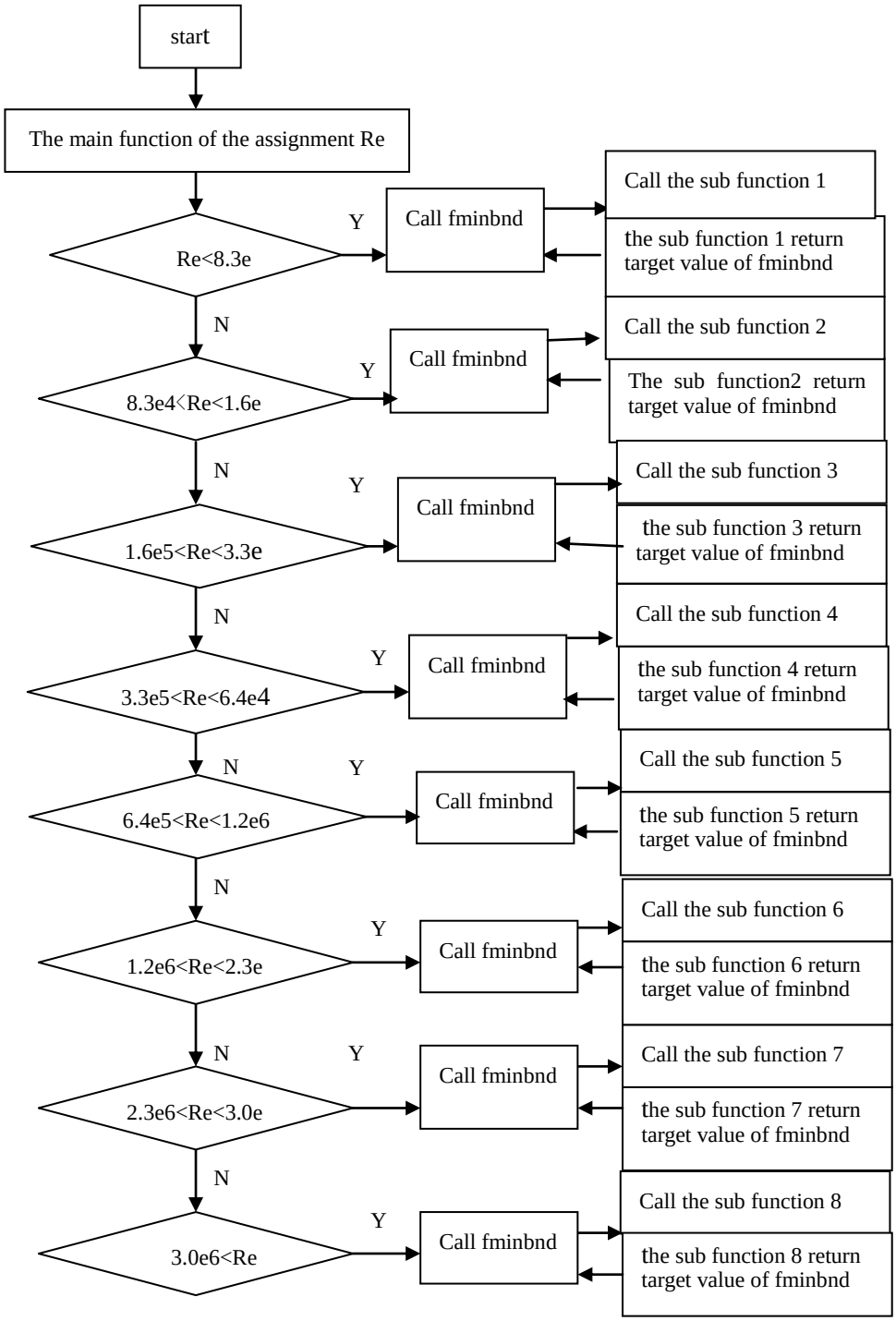

Figure 2. BOB (Ren) Private Function Flow Chart of Program

The above program of BOB (Re) private function are highly versatile. As long as the original airfoil data, we can call the sub function to get any Reynolds number Re, and calculate the corresponding attack angle of the optimal ratio of lift to drag. The calculation of design and performance in the future multiple calls to the sub function. The computer may automatic check required angle, reduce the workload of the designer, but also reduce the error calculation.

1.2.3. Part of the Core Blade Shape Optimization Design Program: In order to calculate the blade geometry, the authors write the design and calculation of the main program. In fact, the optimization design of the blade shape can be attributed to the optimization problem described such as (1-1) and (1-2), which have been discussed in the preceding chapters.

$$dCp = \frac{8}{\lambda_0^2} b(1-a) F \lambda^3 d\lambda$$

$$b(b+1)\lambda^2 = a(1-aF)$$

The core part of the program around these parts, we calculate the geometric parameters of blade after have carry out a, b, and F. This optimization problem is a constrained optimization problem. The first equation is the objective function, the other is constraint condition function. In order to solve this optimization problem [11], we use the Fmincon function in MATLAB advanced language. The Fmincon function for solving constrained optimization problems. The constraints can include linear equality constraint conditions, linear inequalities, nonlinear equality and nonlinear inequality conditions, according the specific conditions to choice. Constraint optimization problem we must solve belong to nonlinear equality constraint. Call the Fmincon function, the first to give the equations in the variables a, b attached to the initial value, then the Fmincon function will be automatic iterative method, until get the maximum and minimum value of objective function, and its corresponding a, b value. We find the initial value by the empirical formula which by consulting relevant literauture.

$$a = \lambda_o^2 / 2000 + 0.027 \lambda_o - 0.038$$

$$b = 10 / \lambda_o \cdot e^{12 r / R}$$

Parameter interpretation

λo——Tip speed ratio;

R—-The rotor radius, m;

r —A section to the wind wheel rotation center distance, m.

In order to meet the need to call the Fmincon function, the author have established objfunw and confunw functions, which were used to store the objective function(1-1)and conditional function(1-2).So, for each blade, we can calculate the interference factor a and b though call the Fmincon function. We can perform geometric operations of leaves with the interference coefficient.

1.2.4. Data Transfer: There are two main function call function in the design of the main program. One part is Fmincon calls indirectly objfunw and confunw, the other one is the main program calls directly to the BOB (Re). In the process of function calls, involves the problem of data transfer is inevitable. How to realize the function of data transmission between? According to the different calling, we adopt a different approach. We set a global variable in the main function and objfunw, confunw, relying on the global variables of the mutual recognition to achieve the data transmission. The main program calls directly to the BOB (Re), mainly rely on the function BOB (Re) in the form of parameters Re, and accept the actual parameters from the main function, and operation returns the results of main function. These data call transfer method has been used in many times in the behind of program design.

1.2.5. The Man-machine Dialogue: In order to improve the compatibility, some of the original parameter were not in the program is set to a fixed value [12]. Such as wind speed V, leaf number N, the wind wheel radius R and tip speed radio λ0, we choose

different values in different design. It is to avoid every design change data into trouble, the author add some simple and man-machine dialogue statement in the initial stage of the main program. The program can be designed based on the original parameters of different with a wider range of applicability. For the calculation of a large amount of data, the main function can automatically create the file and writes the data for analysis in the future.

2. Test and Result Analysis

2.1. Test Method

Research group test designed wind turbine in the vehicle methods [13], synchronous measuring wind speed, current, voltage, rotate speed of wind and other numerical. Among them, the wind, current and voltage can be directly by the meter reading, and speed can be the motor frequency conversion.

2.2. Results Analysis

The author finished all of the dynamic calculation of gas in MATLAB, and designed the variable pitch wind turbine model with diameter of meters.
The design parameters of wind turbine model designed in this paper as follows:

The wind wheel diameter---2 meter; The wind wheel blades—3; The rated power—500w;The number of revolutions--600r/min;The rated wind speed--9m/s;Tip speed ratio—7;Airfoil-- NACA4412

Table 1. Blade Machining Data

Radius	150	250	350	450	550	650	750	850	950	1000
Chord length	160	131	103	81	67	59	54	41	37	16
The torsional angle	22.2	13.3	8.1	5.3	3.4	2.1	0.9	-0.4	-1.4	-1.6

From the chart we can see that the blade that we design is much smaller compared with the common blade, especially tip chord length that the rear of the blade is close to 0mm.The blade has a high utilization rate of wind energy without considering the torque characteristics of wind turbine.

The author drown Power curve after disposing test data. I order to illustrate the problem, we will fix pitch wind turbine output curve and the project design of the variable pitch wind turbine output curves are drawn in the same coordinate system, as shown below:

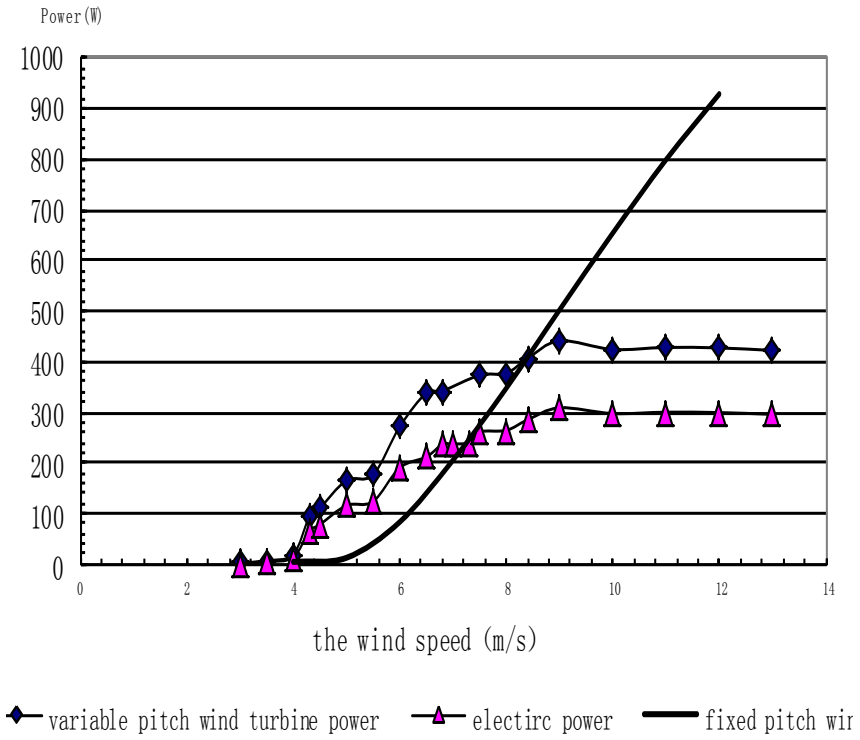

Figure 3. Performance Comparison of Fixed Pitch wind Turbine with Variable Pitch Wind Turbine

From Figure 3 we can see that the output power of the designed pitch wind turbine with fixed pitch wind turbine is improved greatly in the range of the starting wind speed and rated wind speed, and realizes the tracking low wind machine utilization rate of maximum wind energy.

According to the curve of relationship between the measured power wind speed and power, we can get the curve of relationship that wind speed and efficiency of wind turbine, as shown in Figure 4.

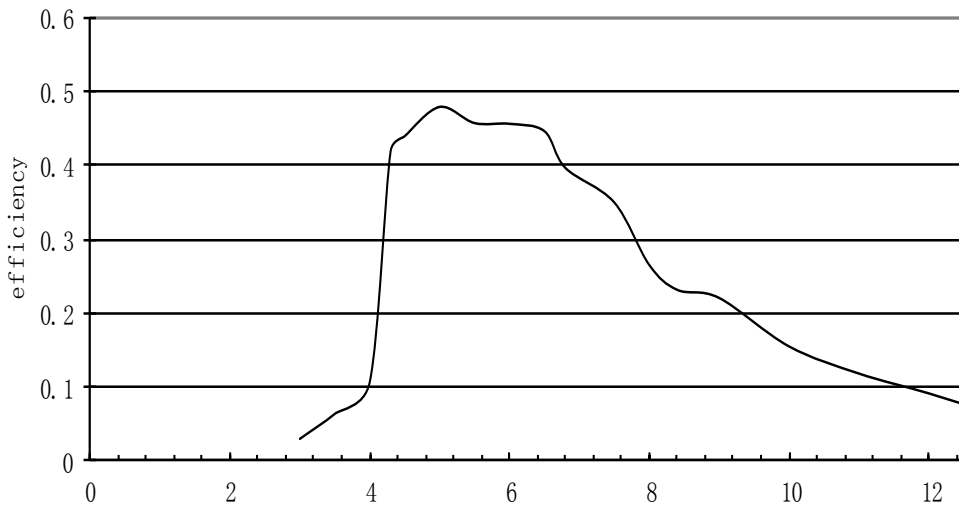

Figure 4. Efficiency Curve

As the Figure 4 as shown that prototype in low wind speed range with high wind energy utilization rate, and can be maintained over a wide speed range. The designed blade with wind energy utilization efficiency and special shape feature, which is not easy to get the starting torque in low wind speed conditions [14]. Ingenious application of spring type variable propeller mechanism make be smoothly done or easily solved this problem, as Figure 3 and Figure 4 shows that.

3. Conclusion

In this paper, author realized the optimization design of high speed wind turbine blade based on Willson algorithm in MATLAB. Proved by experiments that the wind turbine design is able to track the changes of various of wind speed, and overcomes the faults that the fixed pitch wind turbine capture maximum wind energy only in the design wind speed previously, and the wind turbine can obtain higher are bellows the rated wind speed wind.

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