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EFFECT OF TWIST ANGLE OF THE BLADE ON THE PERFORMANCE OF POWER OUTPUT OF THE HORIZONTAL AXIS WIND TURBINES

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ABSTRACT

In the horizontal axis wind turbines, blades are the most important parts of the wind turbine. Wind Turbine is one of the most useful non-conventional energy sources in today's energy crisis scenario. But the initial cost of the Wind Turbine plant is very high. The manufacturing cost of the Wind Turbine blade is about 15-20% of the Wind Turbine plant cost. Different types of loads acting on the Wind Turbine blade are static loads, dynamic loads, fatigue loads etc. Rotation of wind blades mainly depends on the wind speed and the direction of wind. To have optimum number of rotations of the blades the geometry of wind turbine blades are very important. The main parameters in the geometry of wind turbine blades are total length of the blades, cord length of the blades and the twist angle of the blades. Effect of the length of the blade, cord length of the blade and effect of twist angle of the blade on the performance of wind turbine blade are analyzed. The twist angle of the blade is a more sensitive parameter of the wind turbine blades. Little variation in twist angle has more effect on the performance of wind turbine blades. Constrained Gradient (Steepest ascent method) method is used for fatigue life optimization of the blade. The twist angle is very sensitive to the fatigue life of the blade than the chord length and the blade length. The fatigue life increases exponentially with the increase in twist angle, while there is parabolic relation between the fatigue life of the blade and the chord length. The fatigue life decreases with increase in the blade length linearly. Due to increase in fatigue life of the blade, the cost of the wind turbine plant gets reduced with more reliability. Hence the care should be taken about the twist angle of the wind turbine blade while manufacturing. There should always be a optimum twist angle to get optimum power output [1].

Keywords* — *Wind turbine blade, Twist angle, Optimization, Length of blade, Cord length.

I. LITERATURE REVIEW

The wind turbine blades and the structure (tower) are subjected to both static as well as dynamic loads. The wind turbine blades are subjected to fatigue load also. Hence wind turbine blade is an emerging topic to study in recent researches. Numbers of papers are published in order to study different parameters regarding the design of the wind turbine and wind turbine blades. The literature survey indicates that the loads acting on the wind turbine blades are varying in nature. Hence wind turbine blades are subjected to fatigue design. The mean wind speed (mean of wind speed) and the wind turbulence intensity (range of wind speed) are the dominating parameters in fatigue of the blade. The geometry of the wind turbine blade determines the power output as well as the stress distribution over the blade span. Aluminum and steel alloy materials are still used for the small wind turbine blade. Composite materials can be used for wind turbine blades to reduce the weight and to increase the strength. The bending moments are calculated experimentally by using the strain gauges. The empirical formulae are not used till yet to calculate the stresses acting on the blade. Finite Element Analysis can be done using **ANSYS** software. The Finite Element Analysis gives the magnitude of the stresses acting on the blade as well as the location of the blade at which the maximum stresses are acting on the blade. So it is important to find out the geometric parameters of blade which affects the fatigue life of the blade, and also maximize the fatigue life by governing these geometric parameters [2], [3],[4].

II. INTRODUCTION

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation. Humans use this wind flow, or motion energy, for many purposes: sailing, flying a kite, and even generating electricity. The terms wind energy or wind power describes the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks such as grinding grain or pumping water or a generator can convert this mechanical power into electricity. So how do wind turbines make electricity? Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. This aerial view of a wind power plant shows how a group of wind turbines can make electricity for the utility grid. The electricity is sent through transmission and distribution lines to homes, businesses, schools, and so on.

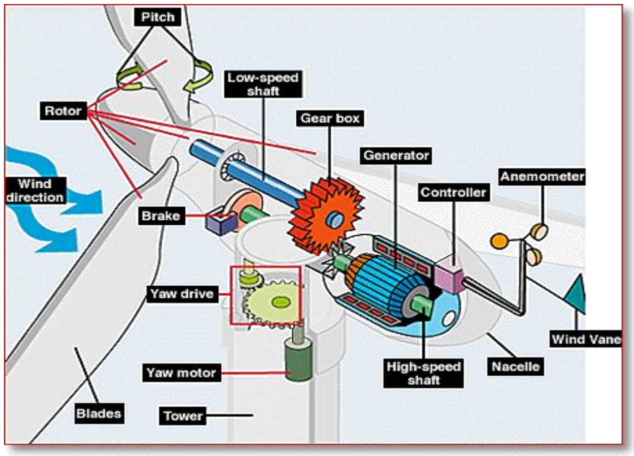

Fig.1.Basics of Wind Turbine

The Anemometer measures the wind speed and transmits wind speed data to the controller. Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate. A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies. The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 65 mph. Turbines cannot operate at wind speeds above about 65 mph because their generators could overheat. Gears connect the low speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes. Generator is used to generate electricity. High-speed shaft drives the generator. The rotor turns the low-speed shaft, the rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working. Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity. The blades and the hub together are called the rotor. Towers are made from tubular steel (shown here) or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind. Wind vane measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind. Upwind turbines face into the wind, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive. Yaw motor powers the yaw drive. As the cross sectional area of the wind turbine blade is of airfoil shape, the aerodynamic forces are acting on the wind turbine blade. These are shown in the figure 2 [6].

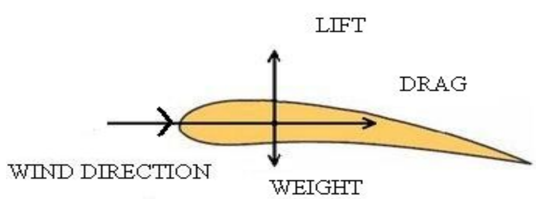

Fig.2.Aerodynamic forces acting on the blade

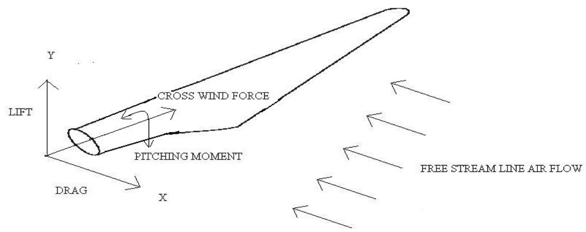

Fig.3. Aerodynamic moment acting on wind turbine blade[5]

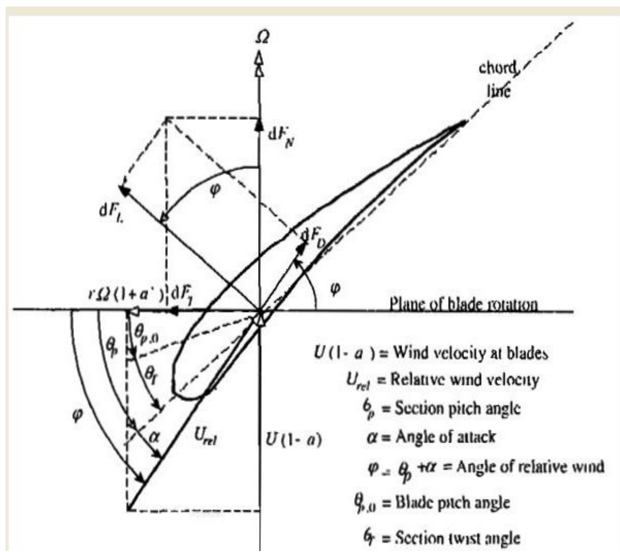

Fig.4. Blade geometry for analysis of horizontal axis wind turbine blade [8]

Modern wind turbines are fatigue critical machines that are typically used to produce electrical power from the wind. These large rotating machines indicate that their rotating components (primarily blades and blade joints) were failing at unexpected high rates, which led the wind turbine community to develop fatigue analysis capabilities for wind turbines. Hence the prediction of service lifetime is becoming an essential part of the design process. The closer to the tip of the blade you get, the faster the blade is moving through the air and so the greater the apparent wind angle is. Thus the blade needs to be turned further at the tips than at the root, in other words it must be built with a twist along its length[9]. Typically the twist is around 10-20° from root to tip. The requirement to twist the blade has implications on the ease of manufacture. Changing of twist angle has significant effect to maximize the power efficiency. Twist distribution can easily be calculated by [10]

$$\theta_i = \varphi_{opt,i} - \alpha_{design}$$

III. OPTIMIZATION TECHNIQUES

Optimization is the act of obtaining the best result under the given circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, optimization can be defined as the process of finding the conditions that gives the maximum or minimum value of a function. Some of the important types of optimization techniques are, Single variable optimization technique, Multi-variable optimization technique, Constrained optimization technique, Specialized optimization technique, Non-traditional optimization techniques [7]. The gradient based optimization technique is preferred in this program. The gradient at the point is obtained by using forward difference method as there is no any explicit relationship between the fatigue life (N) of the blade and the governing parameters of the fatigue life (blade length of wind turbine [L] , chord length of blade [C] ,and the twist angle [Φ]).

IV. INDIRECT SEARCH (ASCENT) GRADIENT METHODS

The gradient of a function is an n-component vector given by

$$\underset{n*1}{\nabla f} = \begin{Bmatrix} \partial f / \partial x_1 \\ \partial f / \partial x_2 \\ . \\ . \\ . \\ \partial f / \partial x_n \end{Bmatrix}$$

The gradient has a very important property. If we move along the gradient direction from any point in n-dimensional space, the function value increases at the fastest rate. Hence the gradient direction is called the direction of steepest ascent. Unfortunately, the direction of the steepest ascent is a local property and not the global one. The negative of the above vector gives the direction of the steepest descent. The direction of steepest ascent method is used for maximization purpose while the direction of the steepest descent method is used for the minimization. Thus any method that makes use of the gradient vector can be expected to give the optimum point faster than one that does not make use of the gradient vector. The evaluation of the gradient requires the computation of the partial derivatives $\partial f / \partial x_i$, i = 1, 2… n. There are three situations where the evaluation of the gradient poses certain problems:

- The function is differentiable at all the points, but the calculation of the components of the gradient, $\partial f / \partial x_i$, either impractical or impossible.
- The expressions for the partial derivatives $\partial f / \partial x_i$ can be derived, but they require large computational time for evaluation.
- The gradient ∇f is not defined at all the points.

Here the function σ is a function of σ (l, c, θ) and there is not explicit relation between the σ and the parameters l, c, and θ. So we have to use the forward finite-difference formula to approximate the partial derivative $\partial f / \partial x_i$ at X_m .

$$\left.\frac{\partial f}{\partial x_i}\right|_{Xm} \cong \frac{f(X_m + \Delta x_i u_i) - f(X_m)}{\Delta x_i}, \quad \text{i= 1, 2,. . . . ., n}$$

If the function value at the base point X_m is known, this formula requires one additional function evaluation to find $\partial f / \partial x_i \big|_{X_m}$. Thus it requires n additional function evaluations to evaluate the approximate gradient $\Delta f \big|_{X_m}$. For better results we can use the central finite difference formula to find out the approximate partial derivative $\partial f / \partial x_i$:

$$\left.\frac{\partial f}{\partial x_i}\right|_{X_m} \cong \frac{f(X_m + \Delta x_i u_i) - f(X_m - \Delta x_i u_i)}{2\Delta x_i}. \quad \text{i = 1, 2, 3… n.}$$

This formula requires two additional function evaluations for each of the partial derivatives. Hence the forward finite-difference formula is used here for minimizing the total computation time.

V. STEEPEST ASCENT METHOD

In this method we start from an initial trial point X_1 and iteratively moved along the steepest ascent directions until the optimum point is found. The steepest ascent method can be summarized by the following steps:

- Start with an arbitrary initial point X_1 . Set the iteration number as i = 1.
- Find the search direction S_i as

$$S_i = \nabla f_i = \nabla f(X_i)$$

- Determine the optimal step length λ_i^* in the direction S_i and set

$$X_{i+1} = X_i + \lambda_i^* S_i = X_i - \lambda_i^* S_i$$

- Test the new point, X_{i+1} , for the optimality. If the X_{i+1} is optimum, stop the process. Otherwise, go to step 5
- Set the new iteration number i = i+1 and go to step 2.

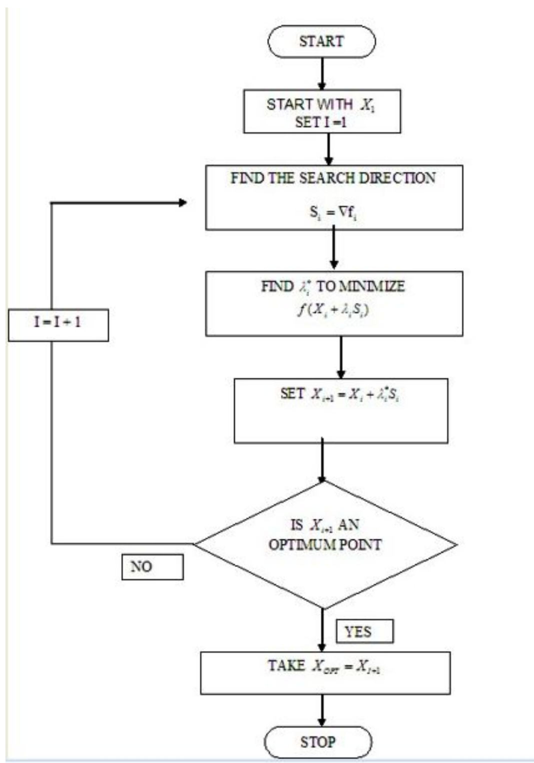

Fig.5. Algorithm for steepest ascent method

VI. OPTIMIZATION OF WIND TURBINE BLADE

Maximize the fatigue life (N) of the wind turbine blade which is under the fatigue stresses due to change in wind speed. Create a model of wind turbine blade such that the fatigue life of the wind turbine blade is optimum without affecting the power (P) extracted from the wind turbine plant. Maximize N, Such that P ≥ P*. Where P* is the predefined power output. Consider (length of blade [l], chord length of blade [c], twist angle [Φ])

Let,

- λ = infinitesimal small length size
- ε1 = small increment in 'l'
- ε2 = small increment in 'c'
- ε3 = small increment in 'Φ'
- P* = predefined power (minimum limit for power output)

Here

$$\nabla N_i = \begin{Bmatrix} \dfrac{\partial N}{\partial c} \\ \dfrac{\partial N}{\partial l} \\ \dfrac{\partial N}{\partial \Phi} \end{Bmatrix} = \begin{Bmatrix} \dfrac{N(c+\varepsilon_1, l, \Phi) - N(c, l, \Phi)}{\varepsilon_1} \\ \dfrac{N(c, l+\varepsilon_2, \Phi) - N(c, l, \Phi)}{\varepsilon_2} \\ \dfrac{N(c, l, \Phi+\varepsilon_3) - N(c, l, \Phi)}{\varepsilon_3} \end{Bmatrix}$$

For the optimization of a horizontal axis wind turbine blade having , The chord length: 1400 mm, The blade length: 8000 mm, Blade material: aluminum, Cut-in wind speed: 5 m/s, Cut-out wind speed: 25 m/s are considered and number of iterations has been carried out.

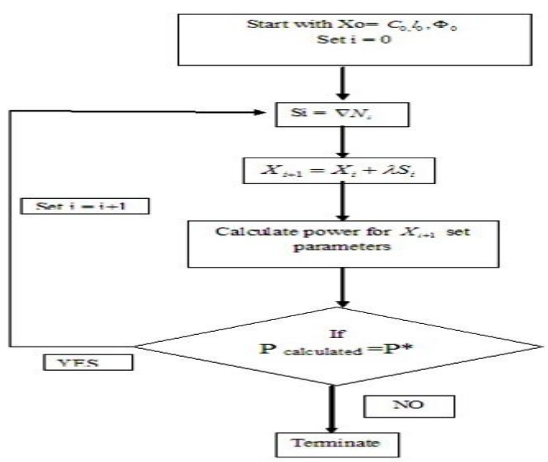

Fig.6. Algorithm for wind turbine blade optimization

VII. CONCLUSION

The fatigue life varies exponentially with the twist angle. The twist angle plays an important role in design of fatigue life as well as the power extracted from the wind. There is an optimum value of twist angle at which both the fatigue life and the power extracted satisfies the design. Fig5. Shows the variation of twist angle. Thus there is an optimum value of the twist angle at which the stresses are minimum which gives the maximum fatigue life. As the Gradient Optimization Technique gives the local optimum solution, the rough design of wind turbine blade is necessary for initial guess of the governing parameters such as initial values of chord length (C), length of blade (L) and the twist angle (Φ).

REFERENCES

1. "H.J.Sutherland "*Inflow And The Fatigue Of The LIST Wind Turbine*" ASME/AIAA Journal of WIND ENERGY 2002. AIAA-2002-0065
2. J. Locke and U. Valencia " Design Studies For Twisted Coupled Wind Turbine Blades", National Institute for Aviation Research ,Wichita, Kansas, Printed June 2004
3. L.D. Nelson H.J. Sutherland "Statistical Analysis Of Inflow And Structural Response Data From The List Program", Sandia National Laboratories, Texas, AIAA-2003-0867
4. P.S.Veers and S.R. Winterstein "Application Of Measured Loads To Wind Turbine Fatigue And Reliability Analysis" ASME Wind Energy Symposium with AIAA Aerospace Science Meeting, Reno, Nevada, Jan 6-9 1997
5. I.H. Abbott and A.E. von Doenhoff, "Theory of Wing Section", Dover, New York (1959)
6. Spera D.A. "Wind turbine Technology: the fundamental concepts of Wind Turbine Engineering", ASME Press, New York,1994"
7. S.S.Rao "Engineering Optimization: Theory and practice III edition" New Age International (P) ltd, publishers.
8. Wind Energy Explained, Theory ,Design and Application. J.F. Manwell, J.G. McGowan and A.L. Rogers University of Massachusetts,
9. Liaquat Ali Lehri, Syed Mushtaq Ahmed Shah "Wind Potential Assessment and Optimization of Wind Turbine Blade for Coastal Area of Jiwani Balochistan Pakistan"International Journal of Materials, Mechanics and Manufacturing, Vol. 1, No. 2, May 2013
10. M. Predescu1, A.Bejinariu2 "Influence of the Number of Blades on the Mechanical Power Curve of Wind Turbines" International Conference on Renewable Energies and Power Quality (ICREPQ'09) Valencia (Spain), 15th to 17th April, 2009.

AUTOBIOGRAPHY

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