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Structural Design Optimization of Horizontal Axis Wind Turbine Towers

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1. INTRODUCTION:

Attributable to the quickly expanding interest of energy, Energy era suppliers perceived the significance of renewable energy. The utilization of wind to deliver energy is one of the real types of renewable energy. Indeed, wind vitality is the main renewable energy which becomes speedier than anticipated. One noteworthy preferred standpoint of wind energy is that it is considerably monetary method for delivering energy. Renewable energy is energy which comes from natural resources such as sunlight, wind, rains, tides, waves & geothermal heat which are renewable (naturally replenished). About 16% of global final energy consumption comes from renewable, with 10% coming from traditional biomass, which is mainly used for heating, & 3.4% from hydroelectricity.

To extract energy from wind, Wind turbines emerged as one of the most efficient ways of converting the kinetic energy in wind into mechanical power [13]. Many energy providers invested in research and development of wind turbines. Now a day's wind turbines are installed in many countries. However, during the last decade many wind turbine damage occurs due to the structural failure of wind turbine towers. Majority of these failures are caused by the strong wind striking the structure or wind induced vibrations. Others are caused by high stresses and buckling loads. Wind turbine towers are designed as thin-walled structure having thickness very less than the diameter. In order to reduce the weight of tower, the vertical dimensions of the tower is relatively large compared to its horizontal dimensions.

This slender nature of wind turbine tower makes it more sensitive to wind loading. There are many different configurations in which wind turbine support structure is designed. It common practice to design wind turbine towers as taper tubular column since they are give more stability to tower against the wind loads and to save the material[11].

2. Scope of project

The extent of this exploration based task is to comprehend the solidness against the wind loads and other auxiliary outline model (buckling, deflection, stress and natural frequency) to accomplish the most extreme dependability of wind turbine tower. It likewise incorporates limited component investigation and systematic examination of two diverse wind turbine bolster structure. Furthermore, the report likewise incorporates a brief writing about the significance of establishment plan in strength of wind turbine tower.CH I) contains brief introduction wind turbine system. CH II) contains the methodologies adopted in designing wind turbine tower.

It discuss about the basic assumptions, design variables and pre-assigned variables. It also summarizes the two tower model on which calculations are performed latter. CH III) contain the design requirements of wind turbine towers. Buckling theories and design codes, stresses, Limitation on deflection and natural frequency. CH IV) summarizes about the wind loads. It contains wind data, wind profile shapes and formulation of wind loads. Ch V) contains finite element analysis of wind turbine tower.

CH VI) contains the numerical analysis of wind turbine tower. CH VII) gives conclusions about the results obtained by finite element and numerical analysis.

3.Objective of project

The goal of this anticipate is basically to comprehend the fundamental configuration parts of wind turbine towers and procedures to accomplish most extreme soundness by utilizing diverse configuration criteria's and standard, and confirming these basis with the assistance of limited component programming.

Wind as renewable source

The use of wind energy is increasing at an annual rate of 20%, with a worldwide installed capacity of 238,000 megawatts (MW) at the end of 2011, and is widely used in Europe, Asia, and the United States. The use of wind to produce energy is one of the major forms of renewable energy. In fact, wind energy is the only renewable energy which grown faster than predicted. One major advantage of wind energy is that it is substantially economic way of producing energy.

4. Working of wind turbines

Wind power is the conversion of wind energy into a useful form of energy. A blade acts much like an airplane wing. When the wind blows; a pocket of low-pressure air forms on the downwind side of the blade. The low-pressure air pocket then pulls the blade toward it, causing the rotor to turn. This is called lift. The force of the lift is actually much stronger than the wind's force against the front side of the blade, which is called drag.

The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity [13]. Wind turbines can be used as stand-alone applications, or they can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility scale sources of wind energy, a large number of wind turbines are usually built close together to form A wind plant. Several electricity providers today use wind plants to supply power to their customers. Stand-alone wind turbines are typically used for water pumping or communications. However, homeowners, farmers, and ranchers in windy areas can also use wind turbines as a way to cut their electric bills. Small wind systems also have potential as distributed energy resources. Distributed energy resources refer to a variety of small, modular power generating technologies that can be combined to improve the operation of the electricity delivery system.

Components of wind turbine

A wind turbine is made up of the following components:

Foundation

In order to guarantee the stability of a wind turbine a pile or flat foundation is used, depending on the consistency of the underlying ground.

Tower

The tower construction doesn’t just carry the weight of the nacelle and the rotor blades, but must also absorb the huge static loads caused by the varying power of the wind. Generally, a tubular construction of concrete or steel is used. An alternative to this is the lattice tower form.

Nacelle

The nacelle holds all the turbine machinery. because it must be able to rotate to follow the wind direction, it is connected to the tower via bearings. the buildup of the nacelle shows the manufacturers has decided to position the drive train components (rotor shafts with bearings, transmission, generator)

Rotor Blade

The rotor is the component which, with the help of the rotor blades, converts the energy in the wind into rotary mechanical movement. Currently, the three-blade, horizontal axis rotor dominates. The rotor blades are mainly made of glass-fibre or carbon-fibre reinforced plastics (GRP, CFRP).

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The blade profile is similar to that of an aero-plane wing. They use the same principle of lift: on the lower side of the wing the passing air generates higher pressure, while the upper side generates a pull. These forces cause the rotor to move forwards, i.e. to rotate.

Hub

A wind turbine hub, a fairly simple mechanism of the wind system, connects the motor with the blades using a gear to move the motor.

Transformer (this is not a part of the Wind Turbine)

5. Methodologies

In fact, there are no simple criteria for measuring the above set of objectives. However, it should be recognized that the success of tower structural design is judged by the extent to which the wind turbine main function is achieved. The different optimization methodologies considered. Each methodology differed, however, in selecting a criterion to be optimized[3].

Minimization of the Tower's Mass

A minimum weight structural design is of paramount importance for successful and
economic operation of a wind turbine. The reduction in structural weight is advantageous from the production and cost points of view.

Maximization of the Tower's Stiffness

The main tower structure must possess an adequate stiffness level. Maximization of the stiffness is essential to enhance the overall structural stability and decrease the possibility of fatigue failure. For a cantilevered tower, stiffness can reasonably be measured by the magnitude of a horizontal force applied at the free end and producing a maximum deflection of unity.

Maximization of the Tower's Stiffness to Mass Ratio

Maximization of the stiffness-to-mass ratio which is directly related to the physical realities of the design is a better and more straightforward design criterion than maximization of the stiffness alone or minimization of the structural mass alone

Minimization of Vibrations

Minimization of the overall vibration level is one of the most cost-effective solutions for a
successful wind turbine design. It fosters other important design goals, such as long fatigue life, high stability and low noise level.

Minimization of a Performance Index that Measures the Separation Between the Structure's Natural Frequency and the Turbine's Exciting Frequency

Reduction of vibration can be achieved by separating the natural frequencies of the structure
from the exciting frequencies to avoid large amplitudes caused by resonance.

Maximization of the System Natural Frequency

The phenomenon of resonance needs to be avoided to safeguard against the failures due to large amplitude responses, stresses and strains. The frequency of excitation cannot be changed as it is directly related to the operational requirements of wind turbine rotor. Hence the only way of avoid resonance is to control the natural frequency of the system.

Another alternative for reducing vibrations is the direct maximization of the system natural frequencies. Higher natural frequencies are favorable for reducing both of the steady-state and transient responses of the tower. Different research studies were done in the past on these optimization techniques it was found that the maximization of tower natural frequency yields the most favorable results.

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6. TOWER DESIGN

The most obvious one is that it places the wind turbine at a certain elevation where desirable wind characteristics are found. It houses many electrical components, connections and the control protection systems and provides access area to the wind turbine. Most importantly, the wind turbine tower supports the wind turbine (a nacelle and a rotor) and carries the loads generated from the turbine. The structural properties of the wind turbine tower are very important as the property such as tower stiffness has a big influence on the performance and structural response of the wind turbine. Tubular towers can have either a round or a polygonal cross section. They can have an upwards (conically or stepwise) tapered geometry, which takes into consideration the smaller bending moment at the upper part.

Modern wind turbine towers are tapered tubular tower; they have diameter increases towards the base. Generally, the idea is to increase the strength towards the base where high bending stresses are susceptible. Also, it saves the material and thereby reducing the cost of the tower[15]. Usually, the tubular of wind turbine tower has a large the ratio of height (H) to least horizontal dimension (D) that makes it a particularly more slender and wind sensitive than any other structures. On the other hand, the thickness is less than the radius of the tubular of shaft; hence the tower is more prone to buckling.

Height of the Tower

The height of the tower is a site-dependent parameter because it is upto the wind characteristics of the site. The design optimization for the least cost could favor tall towers in low wind areas and shorter towers in high wind areas. However, if there are obstacles such as trees or tall objects that may make the wind more turbulent, taller tower will be required. In addition, tall towers may prevent the turbine from the effect of wind shear if the site has frequent wind shear occurrence.

Tower Design Requirements

The tower design is based primarily on types of load acting on the tower. These loads include[16]:

a) Dead Load: loads acting from the rotor, nacelle and additional equipment at the top of the tower.

b) Lateral Load: loads acting on the tower due to wind. This include wind shear which is may be uniform or linearly acting along the height of the tower or it may be varying by a cubic polynomial function.

To counter these loads the tower must have adequate:

i) Axial Strength: The critical load capacity of the tower in the axial direction must be greater than the applied axial loads by a factor of safety.

ii) Flexural Strength: The flexural strength of the tower must be greater than the bending strength i.e. it can sustain moment generated by the wind force. Also it can sustain local buckling moment taking into account the slenderness of the tower. Certain limitations are also applied on the tower cross-sectional dimensions and on tower top deflection and rotation. A satisfactory tower design must meet all the above design requirements.

Buckling of Columns

"Buckling is instability of equilibrium in structures that can occur from compressive load or stresses. A structure or its component may fail due to buckling at a load much smaller than the load which is produce material strength failure" [11]. Wind turbine towers are thin-walled structure which is made from thin-plates joined along their edges. The thickness of the plate is significantly small compared to other cross-sectional dimensions which are in turn small compared to the overall geometric dimensions. For a given column length and cross-sectional area, the designer can either avoid local buckling by using low b/t (width to thickness) ratios or avoid global buckling by using high b/t ratios. However, in the first case the global buckling load will be relatively small.

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Thin-walled structures are susceptible to local buckling if in-plane stresses reach their critical values. Local buckling is manifested by localized deformations of the geometry of the structure. However, if a thin-walled column is made sufficiently long it may suffer global buckling before it experiences local buckling. This means that thin-walled structures must be designed against both local and global buckling. Theory and experiments show that the local and overall buckling phenomenon can interact and when this happens the buckling load can be depressed below the value of individual buckling loads. Practically buckling loads are as low as 30% of the theoretical load. This is due to the fact that:

(a) Boundary conditions
(b) Pre-buckling deformations
(c) Geometric imperfections
(d) Load eccentricities

For axially compressed isotropic cylinders, small load eccentricities do not have a major influence on the buckling strength (Simitses, 1985 et al)[11]. The single dominant factor contributing to the discrepancy between theory and experiment for axially compressed isotropic cylinders is initial geometric imperfections. Now we discuss some major buckling theories we can use while designing a tower against buckling. We now examine each of the theory and determine which of these theory suits over stability criteria's for tubular wind turbine towers.

Euler's Buckling Theory

Euler, in 1744, determined the critical load for an elastic prismatic bar end-loaded as a column from [10] Where Pcr=critical load at which bar buckles, E=Modulus of elasticity, for steel, I=Moment of inertia of bar cross-section, L=column length of bar.

Perry Robertson Equation

There are many formulas that are been derived which give more accurate or realistic result than the Euler's formula. One of them is Perry Robertson formula Where η= CO y/ k2 CO is the initial out of straightness The formula is based on the assumption that the column is initially bent with the maximum offset of CO.

Local Buckling Of Tubular Structures

We have already stated some of the most widely used buckling theories but, those theories are very much related to the overall or global buckling of columns. When we design structures with high slenderness ratio local buckling is much more prevalent than global buckling. In using steel tubes for structural members two considerations may be of importance. First, local buckling should be prevented at stresses below yield-strength, and second, a more severe restriction, is that the tendency to buckle locally should not reduce general buckling load of a tubular member.

Local buckling stress of tubular structures with thin walls under uniform compression can be determined theoretically. Under ideal condition this stress is Where r is the mean radius, t is the thickness, and k is 0.6. However, tests indicate that tubes can actually develop only a fraction of this stress because buckling of cylindrical tube is highly sensitive to initial imperfections [11]. Imperfections resulting from fabrication indentations, joint seams, and similar disturbances can greatly reduce the buckling stress. Even for seamless round tubes, a more realistic estimate of local buckling stress is obtained by using k=0.12. So,

Buckling Stress Criteria's

Apart from different buckling theories there are some other standards, codes and empirical relation for determining critical buckling loads.

According to brazier's theory

The value of critical local buckling stress of all tower sections must be higher than the yield stress of the tower material to prevent the occurrence of local buckling in the elastic region.According to brazier's theory moment required for local buckling is less than the brazier moment [17].

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According to Eurocodes

The design values of compression force (NED) must be less than the buckling resistance of compression member (Nb,Rd) [12].

For cross section with classes 1, 2, 3:
For cross section with class 4:
For cross section with classes 1, 2, 3:
For cross section with class 4:
Where is the reduction factor = 1.0
33
Where
α is the imperfection factor
λ is the non-dimensional slenderness

Allowable Buckling Stress Method:

The allowable local buckling stress method involves (Burton, Sharpe, Jenkins, and Bossanyi) [2]:
1) Calculating the elastic critical buckling stress of a cylindrical steel tube, which has modulus of elasticity Es, wall thickness t, and mean radius rm,
2) Calculating critical stress reduction coefficients for bending and axial loading 34
Where,
αB is bending coefficient
αo is axial loading coefficient
3) Putting these values along with the material's yield strength fY to obtain the allowable local buckling stress. The maximum principal stress in the structure should not exceed this allowable local buckling stress value in order to avoid local buckling.

Results:

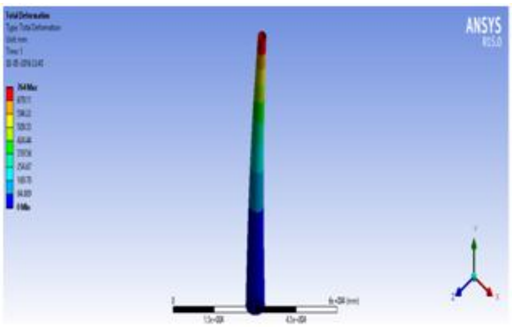

Fig.1Deflection Analysis(4)

Tower top deflection is 764mm

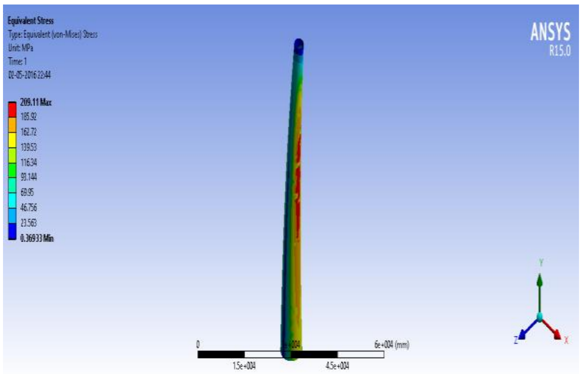

Fig.2 Maximum Yield Stress (4)

Max yield stress = 209.11MPA

7. CONCLUSION

In this work we model different tower design (constant thickness or variable), the major design factor is based on the buckling load and buckling stresses under the constraints of deflection. Specific conclusions from this work include:

1 Shape of the Tower

The tapered tubular tower with constant thickness is better than the constant diameter tubular tower, since its safe tower material and reduces cost.

2 D/t Ratio

The tower becomes more prone to local buckling as the d/t ratio increases. In order to design the tower against local buckling the d/t ratio should be minimum as possible. However, it should be kept in mind that at smaller cross-section the critical buckling load reduced significantly. So, d/t ratio should be chosen with respect to both critical buckling load and allowable buckling stress.

4) Maximum Stresses Occur at the Base of the Tower

While designing a wind turbine tower it should be kept in mind that the maximum stresses occur at the base of the tower (fixed support end). So tower should have high strength at the base.

5 Variable Thickness Along the Tower Height

We earlier conclude that tapered tubular tower have high strength at the base. It is also possible to have variable thickness tower; thicker at the base and as we move up along the tower height, thickness gradually decreases. We know that the maximum stresses occur at the base and as we move up the stress magnitude decreases, so the tapered tubular with variable thickness is also an economical option which reduces both material and cost.

Even though this work is limited only to the design and stability of towers in static conditions this work can be extend if one takes wind velocity as a function of time and similar effects like vortex shading or wind induced vibrations i.e. dynamics analysis. Also the effect of tower connections, bolts and weld can be taken into account to give more sophisticated design of tower. Similarly, a wind turbine tower is designed for a particular rotor which operates at a certain speed and frequency. The effect of rotor and blade forces, especially the rotor thrust becomes significant as the size and weight of wind turbine increases.

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