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DESIGN AND ANALYSIS OF A 10KW WIND TURBINE TOWER

[1]SATISH KUMAR SANGASURI, [2]L. SRIKANTH B, [3]R. A. SAVANUR

[1]M.Tech student, Department of Mechanical Engineering, BLDEA's V.P. Dr.P.G.Halakatti College of Engineering and Technology, Vijayapur
[2]Sr. Scientist, Center for Societal Missions and Special Technologies Division, CSIR National Aerospace Laboratories, Bangalore
[3]Professor, Department of Mechanical Engineering, BLDEA's V.P. Dr.P.G.Halakatti College of Engineering and Technology, Vijayapur
E-mail: [1]satishsangasuri@gmail.com, [2]lsrikanth99@gmail.com, [3]rasavanur@yahoo.co.in

Abstract - The wind turbines are used to convert the wind energy into electrical power. Wind turbines are mounted at the top of the vertical structure called wind turbine tower. With increasing demand of sustainable energy, the production of wind power by using wind turbines have become increasingly important over the last few decades. The use of wind to produce energy is one of the major forms of renewable energy. The primary reason behind the increase in wind energy harnessing capacity is improved turbine technology. However, the development of a wind turbine involves design of several components, including the tower, blades, nacelle, and foundation to be able to successfully harness the wind energy.

In the present work, an attempt has been made towards design and analysis of a 10kW wind turbine tower. The tower structure is 35 m height and has a tubular shape with variable cross section and constant thickness of the wall along its height. This work includes the design considerations and analytical derivations to arrive at the tower design satisfying the required function of supporting a 10kW wind turbine at a Class IV windy site. The critical design case is identified with the help of IEC 61400-2 standards and used to design the tower segments. The design has been carried out by analytical means and have been used as inputs to analysis using FEA (numerical) approach. The deflection equation for a tapered tubular beam has been derived from first principles relating the diameters of the tapered tower at the two extreme ends. The other parts of the tower such as the flanges, gussets, bolts and welded joints were also designed analytically. The tower was modelled using Solid Edge and static analysis was carried out using ANSYS workbench. Further, modal analysis was also carried out. Two tower configurations were analysed viz. (1) monopole (2) tower with perfectly bonded joints. The results of both the analytically and FEA predicted values were compared. Good agreement was observed and the deviations were on account of the assumptions made in the theory that resulted in higher stiffness for monopole tower vis-a-vis the tower with perfectly bonded joints. The door opening in the tower has been studied and remedial measures have also been suggested.

Keywords - Wind turbine, Wind loads, Tip deflection, and Stresses.

I. INTRODUCTION

Owing to the rapidly increasing demand of energy, Energy generation providers recognized the importance of renewable energy. 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.

The primary reason behind the recent peak of wind energy capacity is due to improved turbine technology. Several components of wind turbine must be taken into account, including the tower, blades, nacelle, and foundation designs. New development in the construction of taller structures using better, lightweight materials, and improved turbine design techniques have allowed todays taller turbines to tap better winds at higher elevations for reduced costs. As a result of improved turbine design using lighter-weight steel for the tower, lighter foundations can be used in turn reducing costs. It is imperative to continue improving the design of the wind turbine in order to harvest better energy and its cost.

Wind turbine tower

The tower of a wind turbine supports the nacelle and the rotor and provides the necessary elevation of the rotor to keep it clear off the ground and bring it up to the level where the wind resources are. The towers for large wind turbines are typically made of steel, but concrete towers are sometimes used. Nowadays, most towers are tubular towers, however, lattice towers are also in use. Guyed towers are used for relatively small wind turbines only. The tower is usually connected to its supporting foundation by means of a bolted flange connection or a weld

II. EXPERIMENTAL

2.1 Basic assumptions made for designing wind turbine tower

1) The basic structural model of the tower is represented by an equivalent long, slender cantilever beam built from segments having uniform cross-sectional properties. The tower is cantilevered to the ground, and is carrying a concentrated mass at its free end approximating the inertia properties of the nacelle/rotor unit. This mass is assumed to be rigidly attached to the tower top.

2) Material of construction is linearly elastic, isotropic and homogeneous. The tower has a thin-walled circular cross-section.

3) The Euler-Bernoulli beam theory is used for predicting deflections. Secondary effects such as axial

and shear deformations, and rotary inertia are neglected.

2.1.1 Choice of tower diameter and thickness

Criteria: Minimization of deflection and self-weight. Reduction in self-weight results in cost savings.

After many iterations the following six configurations were shortlisted and the optimum from these was selected.

Diameter (mm)	Thickness (mm)	Self-weight of the tower (N)	Tip deflection (mm)	Ratio of deflection to self-weight
675	14	79377	497	0.00626
1000	7.5	63849	391	0.006123
1250	5	58711.9	370	0.006301
1500	**3.3**	**52608.5**	**232**	**0.004409**
1750	2.8	49442.58	261	0.005226
2000	1.7	47976.5	330	0.006878

Table 1: Choice of tower diameter and thickness

From table 1 it can be seen that the diameter D1 corresponding to 1500mm with shell thickness of 5mm appears to be the optimum configuration based on the deflection per unit self-weight parameters therefore this configuration has been chosen for design.

2.2 Tower top deflection

Assuming wind turbine tower as a cantilever beam the tower top deflection δ can be calculated by applying uniformly distributed loads along the height of the tower.

The obtained tower top deflection δ must be less than 1% of the total height of the tower.

The deflection equation for the case of hollow tapered beam (which is the tower in this case) has been derived from the first principles [3], since the equation was not found in any open literature.

The maximum deflection of the hollow tapered cantilever beam is obtained as below.

$$V = \frac{1}{27} \text{x} \left[\frac{Pl^4}{\pi E t d_m^3} - \frac{48}{l} \right]$$

Where,

V= Deflection of tower top

P = Wind load on the tower = 68068.35 N

l = Length or height of the tower = 35 m

E = Young’s modulus of the material = 200Gpa

t = Thickness of the tower = 5 mm = 0.005 m

d_m = Mean diameter of the tower = (0.5+0.49)/2 = 0.495 m

Substituting all these values in eq (1)

$$V = \frac{1}{27} \text{x} \left[\frac{\left(\frac{68068.35}{35}\right) \times 35^4}{\pi \times 200 \times 10^9 \times 0.005 \times \left(\frac{0.5+0.49}{2}\right)^3} - \frac{48}{35} \right]$$

V = 0.2328 m = 232.8 mm

2.3 Convergence study for deflection of tower

In finite element modelling, a finer mesh typically results in a more accurate solution. However, as a mesh is made finer, the computation time increases. One way is to perform a mesh convergence study.

The following basic steps are required:

1. Create a mesh using the fewest, reasonable number of elements and analyse the model.
2. Recreate the mesh with a denser element distribution, re-analyse it, and compare the results to those of the previous mesh.
3. Keep increasing the mesh density and re-analysing the model until the results converge satisfactorily.

This type of mesh convergence study can be able to obtain an accurate solution.

III. RESULTS AND DISCUSSIONS

3.1 Deflection of tower

3.1.1 Deflection of tower without joints

The calculated result give deflection of the wind turbine tower is 232.8 mm. which is less than the 1% of the height of the tower. This deflection is due to wind loads acting on the tower.

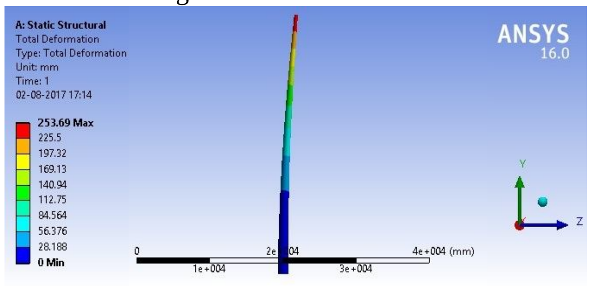

Figure 1: Deflection of the tower without joints in the direction of wind

The figure 1 shows the deflection of the tower modelled without any joints. The maximum deflection in the direction of the wind i.eUy is obtained from the static structural analysis of the tower using ANSYS workbench is 253.69 mm and the maximum deflection in the direction of the wind is obtained from the analytical calculations is 232.8 mm.

3.1.2 Deflection of tower with joints

The figure 2 and 3 shows the deflection of the tower modelled with finite number of joints. The maximum deflection in the direction of the wind i.e. Uy is obtained from the static structural analysis of the tower using ANSYS workbench is 260.22 mm and the maximum deflection in the direction of the wind is obtained from the analytical calculations is 232.8 mm.

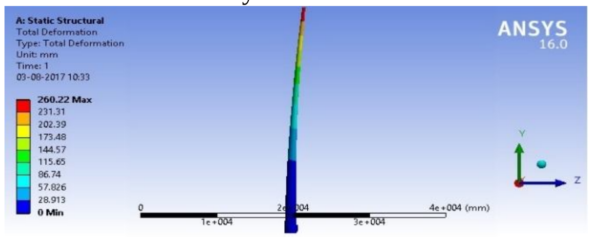

Figure 2: Deflection of the tower with joints in the direction of wind

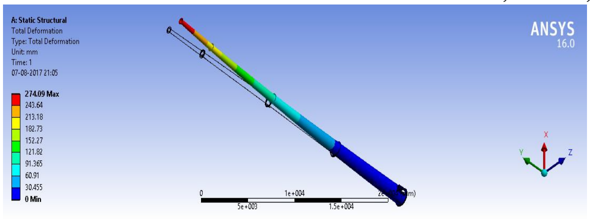

Figure 3: Isometric view of deflection of the tower with joints in the direction of wind

SL NO	Tower Configurations	Tip deflection (mm)		
		Analytical	FEA (Numerical)	% Deviation
1	Monopole tower (Without joints)	232.8	268.93	15.5%
2	Tower with joints	232.8	274.09	17.7%

Table 2: Tip deflection obtained from numerical calculation and FEA

From the table it can be seen that the numerically predicted deflection is lower than that of deflection obtained in finite element analysis (FEA). The analytically predicted deflection is lower by 15.5% than that of FEA. This is because the numerical solution models the wind turbine tower with certain assumptions such as the tower being assumed as one single entity without any joints. Therefore the behaviour is stiffer than that modelled in FEA.
It is also seen from the table that for the tower with joints, the analytically predicted deflection is lower than that of deflection obtained in FEA. The deflection is lower by 17.7% than that of FEA. This is because the numerical solution models the wind turbine tower with certain assumptions such as the tower modelled with finite number of joints. Therefore the behaviour is stiffer than that modelled in FEA.

3.2 Convergence study

3.2.1Monopole Tower

Wind turbine tower is modelled without any joints and mesh convergence study is carried out to obtain the accurate solution. Following figures shows the deflections of the tower for different number of elements.

Results of convergence study of deflection of monopole tower

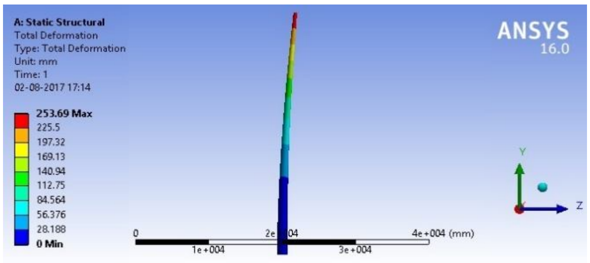

Figure 4: Deflection of tower without joints for 1000elements

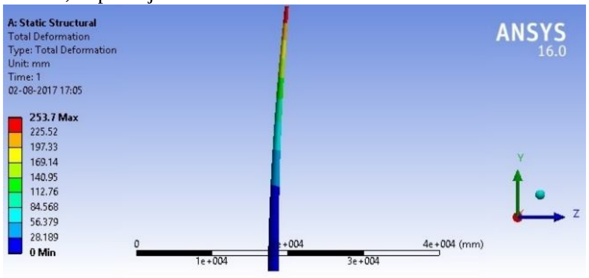

Figure 5: Deflection of tower without joints for 2000elements

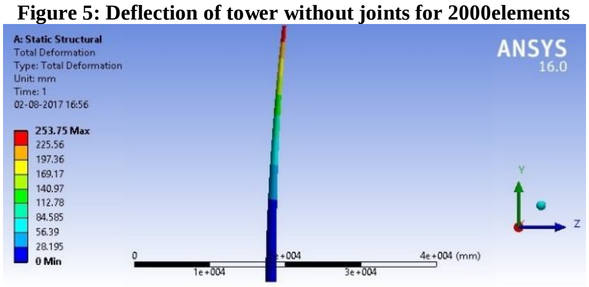

Figure 6: Deflection of tower without joints for 3000elements

From the figures and the table 3 it can be seen that the deflection value varied as the number of elements increased. Initially the tower is meshed with 1000 elements and the mesh size given for 1000 elements is 350mm and the deflection obtained for the 1000 elements of the tower is 253.69. The number of elements increased to obtain the accurate results. The deflection obtained for 2000 elements of the tower is 253.7 and the deflection obtained for 3000 elements of the tower is 253.75. It can be seen that by increasing the number of elements the deflection value also increase. Further increasing the number of elements the deflection values remains same hence these results shows the model is converged.

SL NO	Number of elements	Deflection (mm)
1	1000	253.69
2	2000	253.7
3	3000	253.75

Table 3: Convergence study for deflection of monopole tower

3.2.2 Tower with joints

Wind turbine tower is modelled with finite number of joints and mesh convergence study is carried out to obtain the accurate solution. Following figures shows the deflections of the tower for different number of elements.

Results of convergence study of deflection of tower with joints

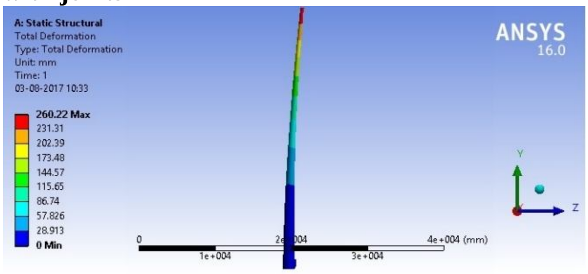

Figure 7: Deflection of tower with joints for 1000elements

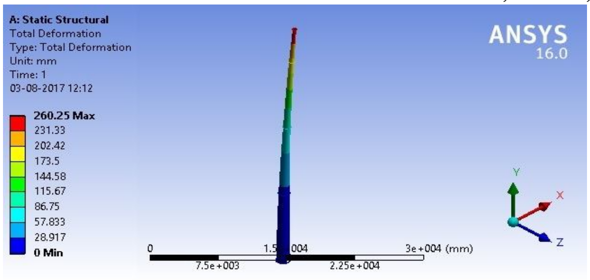

Figure 8: Deflection of tower with joints for 2000elements

From the figures and table 4 it can be seen that the deflection value varied as the number of elements increased. Initially the tower is meshed with 1000 elements and the mesh size given for 1000 elements is 350mm and the deflection obtained for the 1000 elements of the tower is 260.22. The number of elements increased to obtain the accurate results. The deflection obtained for 2000 elements of the tower is 260.25. It can be seen that by increasing the number of elements the deflection value also increase. Further increasing the number of elements the deflection values remains same hence these results shows the model is converged.

SL NO	Number of elements	Deflection
1	1000	260.22
2	2000	260.25

Table 4: Convergence study for deflection of tower with joints

CONCLUSIONS

In this work, a 35m wind turbine tower was designed by analytical means and analysed by FEA using ANSYS software package. The major design considerations was the free end deflection. The design considerations were arrived at as per IEC 61400-2 standards. The analytical solutions were derived and used as inputs for analysis. The finite formulations and the analysis were carried out using ANSYS workbench and the results were presented.

1. The deflection equation for a tapered hollow beam was derived from first principles since the relationship was not found in open literature. Further, an optimum tower diameter, shell thickness based on minimization of self-weight and deflection was determined.
2. The results showed that the monopole tower model exhibited higher stiffness and therefore lower deflection than the tower with perfectly bonded joints. The deviation of FEA prediction is about 15% higher than analytical values. This deviation can be attributed to the assumptions of monopole construction in the analytical calculations.
3. The deflection in case of tower with joints was marginally higher (1%) than monopole tower model which can be attributed to the perfectly fastened joints resulting in lowering of stiffness.

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