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An Analysis of Windmill Structure with SSI

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The generation of energy with higher efficiency is been mandatory to carry out the present domestic and industrial needs of Energy Now a days. Also, the production of energy sources through the Non-conventional Energy sources are increased rapidly, particularly in developing nations like India, Australia, china, UK, etc. Energy production through wind mill (offshore or onshore) has a significant effect in the energy generation. A windmill is, often associating it with the past and particularly before the industrial revolution. Today, things have come full circle, if you will and there is now a growing demand for large, technologically advanced windmills across the world. Nevertheless, higher wind turbine capacity is accompanied by higher wind turbine towers, which are destined to withstand higher wind pressures and are more vulnerable to seismic loads. In the past years, a large number of studies have been carried out to analyze the dynamic behavior of windmill structure under earthquake excitation, in order to improve the stability of wind turbines, but there is still the issue of oversimplification in the geometry of the model. The term wind energy or wind power describes the process through which wind turbine convert the kinetic energy in the wind into electrical energy by the use of generator. All Engineered construction resting on the earth must be carried by a foundation. The foundation is the part of an engineered system which transmits to, and into, the underlying soil or rock the loads supported by the foundation and its self-weight. Windmills although are structurally simple, their behavior under the operating conditions is quite complex due to the static and dynamic effect of wind. Due to the operation of the mill during high wind makes the behavior still more complex. This analysis includes the study of behavior of windmill structure under different seismic conditions.

Keywords: Windmill Structure, Component parts of windmill Structure, types of wind turbine, soil-structure Interaction.

1. Introduction

The need for renewable resources is becoming more evident as the earth's limited reserves of remaining fossil fuels have essentially halted development and utilization. Among renewable energy sources such as wind energy, solar energy, tidal energy and geothermal energy, wind energy is considered to be the most cost-effective alternative energy and one of the cheapest new power sources, showing its great potential to meet demand. [1] The 2021 Global Wind Energy Council (GWEC) released an annual wind report that 2020 was the best year in history for the global wind industry showing 1 year-over-year growth of 53%. Installing more than 93 GW wind power in a challenging year with disruption to both the global supply chain and project construction has demonstrated the incredible resilience of the wind industry. [2] The world of wind power is growing at a phenomenal pace. Projections put the average growth of the industry at 24% for the next five years. [37] Theoretically, wind could produce enough energy to meet global demand. In 2006, however, less than one percent of global electricity consumption came from wind. [3, 4] Global installed wind capacity in 2006 was around 74 Gig watts (GW), according to the World Wind Energy Association [5]. This was more than one percent of global electricity consumption, but because installed capacity does not reflect actual production, its contributions to the global energy mix are less than that. Wind energy capacity is expected to more than double between early 2007 and 2010. [6] Growth will be driven by rapidly developing countries, such as India, Brazil, and China. Several offshore wind parks are being planned in northern Europe and North America. Improving efficiency and falling costs of turbine production and installation will make wind power more price competitive. [7]

The amount of wind energy generated depends mostly on the size, height, type, and location of a wind turbine. Some small turbines, such as those fixed on a sailboat, can generate as little as a few hundred watts - enough to power a few light bulbs. On the other side of the spectrum are the large, utility-scale turbines like the Vestas V90 that produces 3 MW. [8] The foundation is the part of an engineered system which transmits to, and into, the underlying soil or rock the loads supported by the foundation and its self weight. The resulting soil stresses-except at the ground surface- are in addition to those presently existing in the earth mass from the material self weight and geological history. [9,10]

Foundations for windmill are rectangular, square or of a similar configuration. Very high requirements are imposed on windmill foundations with respect to durability and strength. The known windmill foundations are connected to foundation piles whose distance to the centre of foundation is, generally, unequal. In other words, some foundation piles are at greater distance from the central axis of the windmill than other foundation piles. [11, 12]

This uneven loading also has effects on the strength of the reinforcement structure provided in the concrete main part. With the windmill foundations, the reinforcement structure generally consist of the known reinforcing bars or reinforcing steel mesh. The object of the invention is a windmill foundation which, with the strength remaining the same, can be manufactured at a much more favorable cost price. [13, 14]

As stated earlier the wind energy is one of the sources for power production and there is more advancement in the wind mill technology. The height of the wind mills is increased in the recent years to extract more power at higher elevations. [38] Basically two types of tower system such as monopoles or lattice towers are used for the wind mill supporting towers. Each types of tower have its own advantages and disadvantages. As the height of the wind mill increases the thickness of the wall of the monopole towers are increasing and it untimely leads to increase in cost and uneconomical sections. [40] Data from the Iowa Energy Centre shows that at 100 m, wind flows 4.5% faster than it does at 80 m. This would result in an increase in power output of approximately 14%. So it is required to increase the height of wind mill turbine towers, there are basically 2 types of wind mill turbines such as monopoles and lattice towers are used. The monopoles are used for lesser heights of the turbine while the Lattice tower can be used for turbines having lesser mass. [41] If we increase the height of turbine it becomes single degree of freedom system and become dynamically sensitive. So in this study effect of soil is considered for dynamic analysis of the towers. [8]

1.1 Wind as Energy Resource

Wind turbine was one of the earliest non-animal sources of power used by humans. The earliest wind turbine designs were very simple and less complex; turbines were allowed to rotate at a rate corresponding to the wind’s velocity. Wind turbines were used to pump water, grind grain and perform various other tasks. For these purposes, varying speed of the wind turbine impacted the effectiveness of the windmill. Further this clearly justified that controlling the rotational speed of the wind turbine will vary its output. Hence, allowing machines to run at variable speed greatly increased the total energy that can be extracted from the wind. In rural areas of India, the word “electricity” is still like a dream, still millions of people in our country do not have access to electricity in their homes. According to facts, eight out of these ten homes without electricity are situated in far flung villages, some of which are geographically isolated and are often too sparsely populated. Thus, to supply electricity in these rural areas renewable energy like wind power is the cost effective and most feasible solution. In recent years the cost of electric power generated using wind energy has dropped substantially. Since 2004, the price in the United States is now lower than the price of fuel generated electric power. Wind power is growing quickly, at 38%, up from 25% growth in 2002. It is proved to be the fastest growing form of electricity generation. [19]

2. Recent Research in Windmill Structures

Liang Cui, et al (2023) In the current investigation, behaviours of dry sand under dynamic loads were explored. Cyclic loads of strain amplitudes of 0.05%, 0.1%, 0.25% and 0.5% were carried out in a cyclic simple shear apparatus to explore the evolution trend of the stiffness and damping ratio of the soil.

Rose Mary Claire Hawkswood (2021) the experimental modelling was conducted at the University, with five cyclic tests conducted at 1g and one cyclic test at 50g in the 3m beam geotechnical centrifuge. The experimental modelling presented three main behavioural characterised determined from the reaction of the structure, describing changes in the force reaction, foundation profile and foundation-soil contact.

Hicham Boudounit, et al (2020) the scope of the present work, which deal with determining, the natural modes shapes and frequencies of three spars forms during free vibration, as well as for a 5 MW horizontal axis floating wind turbine blade, to prevent and avoid resonance effect, using ABAQUS Finite element analysis software.

Mostafa A. El Absawy, et al (2019) A Finite Element model for variable cross section offshore wind turbine with flexible foundation is developed to accurately determine the fundamental frequency of the tower-nacelle system. The tower is modeled using two-noded Euler beam element with two degrees of freedom, namely transverse displacement and rotation, and Hermite polynomial shape function.

Yan Li, et al (2019) In this research, the scaling parameters including flow field, water droplets, temperature, pressure and rotating parameters were defined. The Weber number (We) based on water film thickness as an important parameter was applied in this study. The icing wind tunnel test indicates that the new rime ice scaling method is an effective method to study the rime ice of large scale rotating blades. This study can be used as a reference for research on anti-icing and de-icing technologies for large-scale HAWTs (Horizontal Axis Wind Turbines).

Jonatan Isaksson, David Tenenbaum (2018) The effect of SSI is modelled with 6 degrees of freedom (DOF) and is implemented via boundary conditions in the open source wind turbine simulation software FAST. The 6 DOF model is representing the foundation-soil system with linear stiffness and damping properties.

Hemal J shah (2017) The wind mill towers are generally constructed using monopoles type tower. The height of tower is more so it becomes single degree of freedom system and dynamically sensitive system. If this towers are constructed on soft soils than the d=effect of soil is predominant in dynamic response of tower, there is possibility of resonance condition in soft soil so in present study dynamic analysis of soil is carried using 3 different types of soil such as hard, medium and soft soil. From study it is concluded that we are getting resonance condition in some soil so we must consider the effects of soil in dynamic analysis of tall structures.

Francesca Taddei, et al (2017) This study presents a practical model for analysis of soil-structure interaction effects on seismic behaviour of wind turbine. The presented model is based on simplified lumped parameter model for the soil-foundation subsystem and is validated against a detailed model, based on a 3D coupled finite element method and scaled boundary finite element method approach. This article shows a demonstrative example for a reference 5MW wind turbine subjected to a seismic event which triggers an emergency shutdown. The application of the lumped parameter model allows a significant model size reduction and accurate approximation of the soil-structure behavior in time domain.

Mohammad-Amin Asareh (2015) In this paper a nonlinear dynamic behavior of a 5-MW NREL wind turbine considering different earthquake and wind intensities using the finite element model. Engineering Demand Parameters (EDP) and Intensity Measures (IM) are then obtained from Incremental Dynamic Analysis (IDA) and used to assess the probability of exceeding different Damage States (DS) using fragility curves.

G. Nikitas, et al (2015) This paper presents a simple and easily scalable loading device that is able to apply millions of cycles of cyclic as well as dynamic loading to a scaled model to evaluate the long term performance. Furthermore, the device is economic and is able to replicate complex waveforms (in terms of frequency and amplitude) and also study the wind and wave misalignment aspects. The proposed test methodology may also suffice the requirements of Technology Readiness Level (TRL) Level. Typical long term test results from two types of foundations (monopile and twisted jacket on piles) are presented to show the effectiveness of the loading device.

B. Gencturk and A. Attar and C. Tort (2014) has studied the various bracing system for 24 meter high lattice tower and he has given the various design alternatives for the 24 meter high lattice tower and its dynamic properties.

B. Song, Y. Yi and J. C. Wu (2014) has studied the effects of the different earthquake on tall wind turbines and he has shown that dynamic response of structure is affected by height. When the height increases the maximum displacement in the top of the tower would increase 231% in 8-degree rare earthquake.

Domenico Lombardi, Subhamoy Bhattacharya, David Muir Wood (2013) has experimentally studied the effects of the soil structure interaction on the wind mills and he has shown that the clayey soils will make the tall structure dynamically sensitive.

Hani M. Negma, Karam Y. Maalawi (2000) has done optimization of 100 kw wind mill tower using different cross sectional areas radius of gyration and height of each segment and the optimum design obtained is applied to design of 100 KW horizontal axis wind turbine.

M. Harte , B. Basu , S.R.K. Nielsen (2012) has studied the effects of modeling the soil and foundation for thewind turbines and he has studied the effect of soil in terms of displacement, base shear ,shear force and bending moment in the turbine and foundation system.

Mohammad AlHamaydeh, Saif Hussain (2011) has modeled the wind turbine of 2 villages located in alsaka considering the soil properties prevailing at site. He has investigated the pile foundation for given site. Researcher has changed the dimensions of pile and spacing of pile and given the foundation design at two different sites. Remi Andre Kjorlaug, Amir M.

Kaynia, Ahmed Elgamal (2014) has modeled 65 KW and 5 MW wind turbine and applied wind and earthquake forces on the wind mill tower. He has also modeled soil at the foundation and he has concluded that soil must be modeled to study the response of the wind mill towers.

Francesco Petrini, et al (2010) Numerical models are developed to assess the safety performance under aerodynamic and hydrodynamic actions. In the structural analyses, three types of turbine support structures have been considered and compared: a monopole, a tripod and a jacket.

3. Structural System Development

3.1 General

Basic objective of this work is to examine the effect of wind and earthquake on windmills foundation rested on different type of soils considering soil-structure interaction. This objective is achieved by modeling and analysis of wind-mill in STAAD-Pro Software. The dimensional data required for the modeling is collected from actual site conditions. [23]

3.2 Physical Data

3.2.1 General

There are two types of wind-mill towers, Lattice and Tubular type. The Lattice type of tower is similar to electric power transmission tower, only the sections used for lattice tower are heavy as compare to transmission tower. The major components are made up of rolled steel sections. These types of towers are not suitable for greater heights. Generally for greater heights tubular types of tower is the only option. They are made up of steel plates of specific thickness molded in the shape of a tube. These types of towers are reliable for any height and hence are generally used for high electric power generation. [24]

- Actual Site Data of Windmill Structure:-

1) Location of Substation Structure:- Tuljapur
2) Substation Capacity :- 220/ 132 kv
3) Total capacity of Windmill Structures:- 100 MW
4) Actual site of windmill Structure: - Lohara, Hippargarava, Dist- Osmanabad.
5) Name of Zone :- Aurangabad
6) Region :- Marathwada

3.2.2 Physical Properties of Wind-mills

At greater heights wind intensity is high, and greater is the electric power generation capacity. Height of wind mill tower changes according to electric power generation. As capacity of power generation changes, size of wind mill (Size of tower, Length of blades, and Size of foundation) changes and weight of the system also changes. [26] Generally the blades of wind turbines are flat, rounded or curved. In generating electricity, a horizontal-axis turbine with three-blade design is most efficient for Energy Generation. [25]

1. Capacity of Windmill Structure:- 2 MW
2. Height of Structure :- 106 m
3. Type of Tower:- Tubular steel tower
4. Material of Tower :- Steel
5. No. of Blades:- 3
6. Type of Turbine:- vertical Axis

3.2.3 Working Wind Velocities

Minimum wind speed required for working of the wind-mill is 3 m/sec and maximum wind speed 25 m/sec. However operation of the windmills stops automatically at velocity 15 m/sec for safe maintenance consideration. While analysis the Design wind speed considered is from 33 m/sec to 55 m/sec. [42, 43]

3.2.4 Foundation Details

There are two types of foundation for wind-mills. Rectangular foundation and Circular type foundation rectangular type foundations are generally used for lattice type of tower and circular foundations are used for tubular type of tower. [44, 45]

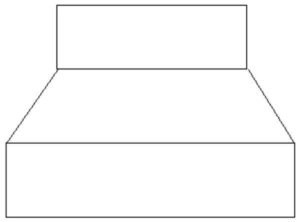

Fig2. Foundations for tubular wind-mills (elevation) [30]

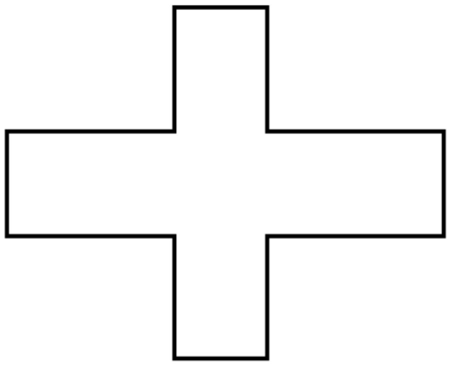

Fig3. Foundation for lattice wind-mills (plan) [30]

3.2.5 Modeling Aspects

3.2.5.1 General

Modeling of the wind mill system is divided into two steps. First step is modeling of foundation and second is modeling of wind mill tower. Finite element modeling technique is used for entire structure. Various elements are used from FEM elements for the modeling. [3]

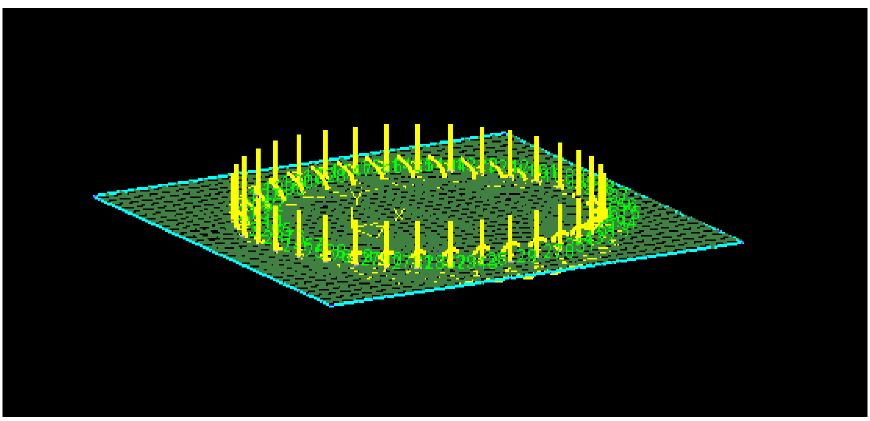

Fig4. Software Modeling of Foundation [3]

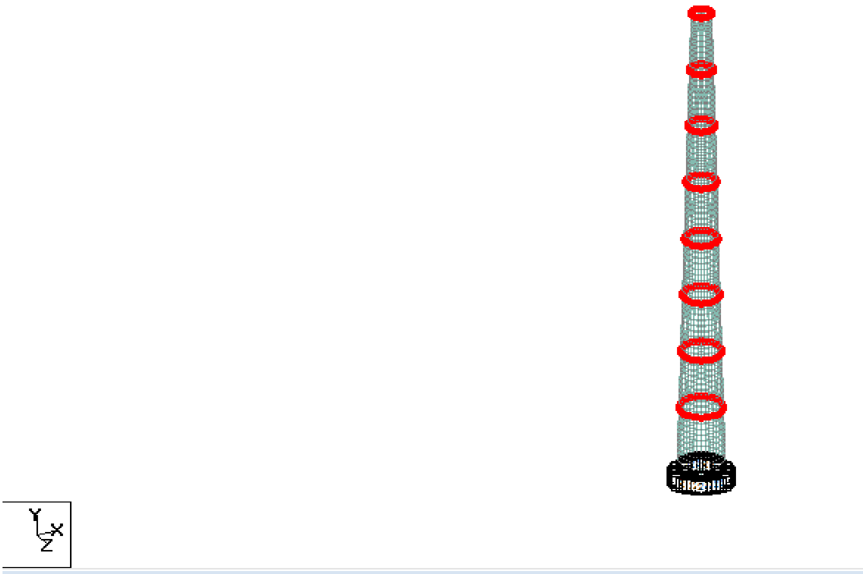

Fig5. Software modeling of windmill Tower [3]

4. Soil-structure Interaction

Soil-Structure Interaction can have a significant impact on large structures and soft soils. SSI can affect the settlement pattern of foundation and behavior of superstructure. SSI analysis can evaluate how a structure will behave to seismic ground motion. [35] This ensures that structure is designed with earthquake without losing its safety. In general in most of the cases interaction causes reduction in critical design values of the shear and moments etc. Forthcoming to SSI problems contains discrete vs continuum, frequency vs time, and linear vs nonlinear. [36]

- Factors to be considered for analyzing the windmill with SSI Effect:-

I. Soil type at greater depths

II. Size of footing

III. Footing Stiffness

IV. Superstructure Stiffness

V. Modulus of Sub-grade reaction

The modulus of Sub-grade reaction is a conceptual relationship between soil pressure and deflection that is widely used in the structural analysis of foundation members. It is used for continuous footings, mats, and various types of pilings. The modulus of Sub-grade reaction is given by

$$Ks = \frac{q}{\delta}$$

Where,

Ks = Modulus of sub-grade reaction

q = Soil pressure and

δ = Deflection

Table2. Soil Properties used for Analysis

(As Per Joseph E. Bowles foundation engineering reference)

Soil Type	Modulus of Subgrade KN/m3	Poisson Ratio	Modulus of Elasticity(N/mm2)
Hard soil strata	96000	0.4	96
Medium soil strata	45000	0.4	45
Soft soil strata	10500	0.4	10.5

5. Conclusion

For Micro capacity wind turbines proper selection of all electrical components such as generator, battery, and inverter plays a major role as well as selection of blade material is very important aspect in accordance to cost estimation, strength & properties of material. Selection of manufacturing process should be done on the basis of blade size, turbine capacity, blade material, manpower available. This work is mainly study on different aspects for harnessing wind energy. It has been suggested that it is desirable to collect wind energy with a device that minimizes maintenance needs, especially as far as distributed generation is concerned. However, from above analysis and results obtained it can be concluded that bladeless wind turbine can be proven as a better alternative for conventional windmills if installed at large numbers since it can produce outputs even at low wind speeds. The effect of the soil is more predominant in case of tall wind mill structures constructed on the soft soil and it can result in resonance conditions during the operation of wind mill towers so stiffness of soil must be considered for dynamic analysis of tower.

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