Study of Interference Effects on Wind Turbine Structures

Sreeram Rajesh

K. Shruti

Sabareesh G.R

P.N Rao

BITS Pilani, Hyderabad
Campus,
Hyderabad, India

BITS Pilani, Hyderabad
Campus,
Hyderabad, India

BITS Pilani, Hyderabad
Campus,
Hyderabad, India

BITS Pilani, Hyderabad
Campus,
Hyderabad, India

sreeramrajesh73@gmail.com

shruti.konka@gmail.com

sabareesh@hyderabad.bits-pilani.ac.in

pnrao@hyderabad.bits-pilani.ac.in

Abstract

In wind farms, turbine structures exist very close to each other which usually enhances or reduces the pressure load on the surrounding structures. This phenomenon, termed as interference effect is therefore important from design point of view. Provisions for considering interference effects while designing of structures are inadequate in wind loading codes and standards. The present paper investigates the interference factors for two wind turbines located in close vicinity and also compares the interference factor of a wind turbine tower with that of a rectangular building type structure. Some key observations made from the results of this study is the nature of variation of interference factor for different wind incident angles when the structures are separated by varying distances. The wind interference factors are observed at different locations on the wind turbine tower and an attempt is made to categorize the various trends observed.

Keywords: *Wind Turbine Structure; Aerodynamic Interference; Interference Factor; Coefficient of Pressure.*

I. INTRODUCTION

The presence of interfering structures in the vicinity can drastically affect the pressure load acting on the primary structure. Interference effect on the structure depends on factors such as terrain category, wind incident angle, geometry and orientation of the structure, spacing between the structure etc. Experimental studies of interference effect between buildings has been carried out by several researchers in the past [2,7,10]. Studies using numerical approach on building [8,9] and wind turbine structures has also been carried out [3,5,6]. The present study aims to investigate the interference effects of NREL Phase VI wind turbine structure. The study adopts a numerical scheme validated by Shruti et.al [1] for flow over building structures. The scheme has already been validated for flow over cooling towers. The present study attempts to extend the scheme to wind turbine structures.

The modelling of Atmospheric Boundary Layer (ABL) as well as the turbulence in the flow domain is important to maintain accuracy of the simulation models. In this study, a User Defined Function (UDF) is used for generating the ABL based on [12] and Large Eddy Simulation (LES) methods [13,14] are used to model the turbulence [2]. During post processing, the value of pressure coefficient (C_p) is extracted at a specific height of the structure and interference factors at this height is computed.

Generally, in the presence of an interfering structure, Fig. 3(b), a wake is formed on the windward side of the principle turbine, which causes the C_p to be lower than expected from an isolated case. The paper considers the value of C_p at different discrete points around the structure at a height $y_h/y = 7.5$ to obtain the value of IF on the wind turbine tower at orientations of 0° , 30° , 60° and 90° . Here y_h and y represents the domain height and height at which pressure coefficients are extracted respectively. The study considers different tandem configurations: $1.5D$, $2D$ and $2.5D$ where D is the diameter of the Wind Turbine Tower. The geometry of the domain, Fig. 3(a), boundary conditions and numerical scheme adopted are discussed in section II and is same as that for the building case considered in [1].

The Interference factor is evaluated using the following relation:

$$IF = \frac{C_p \text{ of Principal Tower in the presence of an Interfering Tower}}{C_p \text{ of Principal Tower in the absence of an Interfering Tower}} \quad (1)$$

II. METHODOLOGY

A. Computational Model

The configuration analysed consists of a principle structure and an interfering structure in tandem arrangement, see Fig. 2. The NREL Phase VI wind turbine structure, see Fig. 1, has been adopted based on a study by [3]. In the current investigation, a horizontal axis wind turbine is taken as the principal structure. The horizontal axis wind turbines finds wider application in generating electricity compared to a

vertical axis wind turbine. Also, usage of vertical axis turbine is limited to a smaller scale (~8-10m, Ref. [4])

Figure 1: Geometry of NREL Phase VI wind turbine

Figure 2: Arrangement of turbines at 0°, 30°, 60° and 90°

All the geometrical parameters used in this investigation were adopted from experimental work carried out in [2] including the size of the computational domain. The dimensions of the computational domain is $X_D \times Y_D \times Z_D = 2.52m \times 1.8m \times 2.2m$ [2]. The blade configuration is adopted from [3] where the numerical procedure adopted is similar for the initial steady state analysis. The NREL Phase VI turbine has a rotor of 10 m diameter and a hub height of 12 m. The simulation model is scaled down to match the height of the typical structure analysed in [2]. The model has a blade diameter of 0.23 m and a hub height of 0.28 m. As the present study also makes a comparison of the results with that of [1], the scale of the structure and the geometrical parameters of the computational domain has been kept same.

While discretizing, the domain has been divided into two regions representing the interior and exterior, Fig. 3. The interior region of the turbine has been divided into fine unstructured mesh so as to adapt easily to the curved geometry of the wind turbine blades. This region has a height of 0.7 m and a diameter of 0.6 m. The exterior region of the turbine has been divided into a structured multizone mesh in keeping with the requirements of the LES turbulence model. The entire mesh has a minimum feature size of $10^{-4} m$ and has been divided into 17.8 million elements.

B. Boundary Condition

The computational domain with the following boundary conditions namely- velocity inlet, pressure outlet, three no slip walls, one ground wall with roughness constant of 0.0005 to model the terrain under consideration and no slip

walls that represents the turbine body. The medium considered is air as an ideal gas at 300 K. An ABL and its turbulence characteristics are defined at the inlet using a UDF with parameter $\alpha=1/4$ [12] for urban terrain category. The mean wind velocity(V) at the inlet is 8.2 m/s and turbulent intensity (I) = 20% at the hub ($h = 0.28m$) of the wind turbine tower, both of which are calculated using $U_G = 9.393$, $Z_G = 0.482$ and $Z = 0.28$ in Eq.1 and Eq. 2 respectively. The value of U_G is fixed based on velocity being equal to 8.2 m/s at the hub height. Z_G is fixed to make the numerical and experimental velocity profile match. The derived turbulence intensity, I , Eq. 2 and associated kinetic energy, k , Eq.3 is also given as boundary condition parameters using a UDF at both the inlet and outlet.

$$U_Z = U_G \left(\frac{Z}{Z_G} \right)^\alpha \quad (1)$$

$$I = 0.1 \left(\frac{Z}{Z_G} \right)^{-\alpha-0.05} \quad (2)$$

$$k = \frac{3}{2} (I \cdot U_{avg})^2 \quad (3)$$

$$\varepsilon = \frac{(U_{ABL}^*)^3}{K(y+y_o)} \quad (5)$$

$$U^* = C_\mu^{1/4} k_p^{1/2} \quad (6)$$

$$k_s = \left(\frac{9.793}{C_{ks}} \right) y_o \quad (7)$$

Where $C_\mu = 0.09$, $K = 0.41$, $y_o = 7.6585 \times 10^{-6}$

Figure 3: (a) and (b) Geometry of the computational domain

Figure 4: Modelled Inlet Wind Velocity Profile

C. Numerical Simulation

The flow is assumed to be transient in nature with appropriate boundary conditions and a suitable turbulence model to capture the fluctuations in time. The governing equation consists of filtered forms of continuity equation and RANS equation [4], which are solved using the applied boundary conditions. The solver is initialized at inlet. SIMPLE scheme is used for pressure velocity coupling. The kinetic energy is calculated using the power law equation and momentum using second order scheme. The simulation is then set under steady state till convergence, which is observed to be less than 300 iterations for all the cases where a convergence criteria of 10^{-4} is used. The initial convergence is obtained through a $k - \epsilon$ turbulence model with realizable enhanced wall treatment. The converged solution is then superimposed onto a transient formulation. Turbulence model adopted for the transient formulation is LES with subgrid scale (SGS) model to filter out eddies smaller than the minimum grid size. The Smagorinsky-Lilly SGS model without dynamic stress option is used to model sub-grid turbulence (smaller eddies). Second order upwind scheme with bounded second order implicit transient formulation is used. The simulation is run for 150 time steps with a step size of 0.0005s, equaling to a total time of 0.075s.

III. RESULTS AND DISCUSSION

A. Comparison between interference factors for a building and wind turbine tower

In the present investigation, to understand and compare the IF between structures with comparable heights existing in real world environments, IF at a height of $y_h/y = 7.5$ has been evaluated on a wind turbine tower and the results are then compared to the IF of a building case at the same height. The distance between two buildings are maintained at $1.5B$ where B is the width of the building base. Corresponding distance between the two wind turbine towers are $1.5D$, D being the diameter of the tower. The maximum values of the IF obtained are then compared with the corresponding building case for different incident wind angles, Fig. 5. Some important observations noted here includes the drastic change in the IF of the building model

at a wind incident angle of 30° . In contrast, the IF of tower model decreases gradually with increasing wind incident angles.

Figure 5: IF of Building vs 1.5D Tower against incident Wind angles.

B. Comparison between interference factors at different tandem configurations

The IFs are compared for different tandem configurations of wind turbine towers, namely 1.5D, 2D and 2.5D at different wind incident angles, see Fig.6. The ratio $y_h/y = 7.5$ has been chosen such that the C_p in the nearby region has minimal variation as compared to regions below. The height ratio was therefore chosen after evaluating the C_p in the regions below.

The IF of 1.5D tower model is observed to decrease from 6 to 1. However, in the 2.5D tower model, there is a drastic jump in the value of the interference factor to 5 at 30° . In contrast, the IF for 2D tower model remains close to 1 throughout.

Figure 6: IF of tower at 1.5D, 2D & 2.5D against incident Wind angles.

C. Comparison of interference factors at different wind incident angles

The IF at discrete positions has then been compared with that of a building case using an s/b method. Here ' s ' is the distance along the outer edge of the structure from the front most point and ' b ' is the tower diameter and building width for the respective cases as depicted by Fig. 7. The simulations are first carried out on an isolated wind turbine at incident wind angles 0° , 30° , 60° and 90° and the C_p values for different s/b ratios around the wind turbine tower at a height of $y_h/y = 7.5$ are extracted.

For the tandem configuration 1.5D, as the wind incident angle increases, the IF has a drastic jump for s/b ratios in the range 1- 1.8 for a wind incident angle 0° , see Fig. 8 (a)

thus indicating a drastic change in load around the building. For the 2D tower model, the IF is restricted to values below 1 throughout, see Fig. 8 (b). Therefore the load variations is less prominent here. The 2.5D tower model has the interference values below 1 for all incident wind angles except at 30° where this value spikes for s/b ratios in the range 0- 0.6, see Fig. 8 (c).

Figure 7: s/b ratio for wind turbine tower and building respectively

Figure 8: (a), (b) and (c) IF vs s/b ratio for 1.5D, 2D and 2.5D for incident wind angle 0° , 30° , 60° & 90° .

IV. CONCLUSIONS

In the present paper an attempt has been made to study the effect of two major parameters that will influence the interfering factor mainly, (a) distance between interfering structures and (b) wind incident angle. Some key observations made through the present numerical study includes (1) the effect of interference becoming less prominent as the wind incident angle increases and as the s/b ratio increases (2) Tandem configuration of 2D yielded minimum wind loads as seen from IF values less than 1 for all wind incident angles and all s/b ratios.

REFERENCES

1. K.Shruiti, Sabareesh G.R, P.N.Rao, "Mitigating Wind Induced Disasters on a group of Buildings and Cooling Towers due to Interference Effect" In Proc of International Workshop on Wind Related disasters and mitigation, Sendai , Japan, 2018
2. Wonsul Kim, Yukio Tamura, Akihito Yoshida, "Interference effects on local peak between two buildings", Journal of Wind Engineering and Industrial Aerodynamics,99(5), ,2011, 584–600
3. Li Li, Linyue Gao, Yongqian Liu, Yansong Cui, " Numerical Simulation of Wake Interference Effects on the Downstream Wind Turbine", IEEE Explorer: <https://doi.org/10.1049/cp.2015.0464>, 2015.
4. Luisa Pagninia, Giuseppe Piccardo, Maria Pia Repetto, "Full scale behavior of a small size vertical axis wind turbine", S0960-1481(18)30440-3, 2017.
5. Thanh Toan Tran, Dong-Hyun Kim and Ba Hieu Nguyen "Aerodynamic Interference Effect of Huge Wind Turbine Blades With Periodic Surge Motions Using Overset Grid-Based Computational Fluid Dynamics Approach", J. Sol. Energy Eng 137(6), 061003
6. P Weihing, K Meister, C Schulz, Th Lutz, E Krämer "CFD Simulations on Interference Effects between Offshore Wind Turbines" J. Phys.: Conf. Ser. 524 012143
7. Yi Hui, Yukio Tamura, Akihito Yoshida, "Mutual Interference Effects between Two Building Models with Different Shapes on Local Peak Pressure Coefficients", 104–106 (2012) 98–108, J. Wind Eng and Industrial Aerodynamics.
8. Atul K. Desai, Jigar K. Sevalia, Sandip A. Vasanwala, "Wind Interference Effect on Tall Building", J. Civil and Env. Eng. Vol:8, No:6, 2014
9. Yuan-Lung Lo,*, Yong Chul Kimb, Yi-Chao Lic "Downstream interference effect of high-rise buildings under turbulent boundary layer flow", 159 (2016) 19–35, J. Wind Eng. Ind. Aerodyn.
10. X.F.Yu, Z.N.Xie, J.B.Zhu, M.Gu "Interference effects on wind pressure distribution between two high-rise buildings", Volume 142, July 2015, Pg 188-197, J. Wind Eng & Industrial Aerodynamics
11. Bert Blocken, Ted Stathopoulos, Jan Carmeliet "CFD simulation of the atmospheric boundary layer: wall function problems", Atmospheric Environment, 41(2): 238-252, 2007.
12. AIJ Recommendations for Loads on Buildings, Ch 6, Wind Loads.
13. S. Vengadesan, P. Nithiarasu, "Hybrid LES – Review and assessment", Sadhana Vol. 32, Part 5, pp. 501–511, October 2007,
14. Tetsuro Tamura " Large Eddy Simulation on Building Aerodynamics", APCWE- VII, 2009