Analysis of response of wind turbine under wind load

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ABSTRACT

The nonlinearity in the wind loading expression can result in a non-Gaussian response. This paper focuses on the method to evaluate the peak factor of the non-Gaussian response of wind turbine under wind load. Firstly, the moment based Hermite transformation method is used to express a standard non-Gaussian process in terms of a standard Gaussian process and its moments. Secondly, the problem of evaluating the peak factor is simplified to the problem of evaluating the third order moment or the skewness of the response distribution. Thirdly, by considering the ideal case with no resonance and the relation between skewness and the resonance-background ratio Rd , the formula for skewness is proposed. Finally, wind response simulation for wind turbine model is carried out to confirm the formula's accuracy.

INTRODUCTION

Wind load on structures are usually calculated by quasi static method which uses a coefficient called the peak factor. The peak factor accounts for the ratio of maximum fluctuating wind load and the standard deviation of wind load. An expression of peak factor for a Gaussian process has been proposed by Davenport. However the Gaussianity assumption which is apliabe only when the nonlinear component in wind load is neglectable may lead to an underestimation of peak factor and of extreme load (Kareem et al.). As more wind turbine are being errected in area with complicated terrain where wind turbulence intensity is high, the effect of nonlinear component is unneglectable. It is therefore necessary to evaluate the peak factor of the response of wind turbine under wind load without Gaussianity assumption.

The evaluation method for peak factor has been discussed by Ishikawa who proposed a method to calculate the peak factor considering spatial correlation using the moment based Hermite transformation method and the definition of peak factor proposed by Nishijima et al. However, this method is limited to structures with neglectable resonant response. But in the case of wind turbine , because of its low structural damping ratio, the effect of the resonance part is significant.

This paper proposes a method to calculate the peak factor of the response of wind turbine under wind load which consider both the spatial correlation of wind speed and the resonant component of the response.

WIND LOAD ON WIND TURBINE

In this study the model in fig.1 is used. In this model the first mode of tower is considered and the rotor is assumed to be rigid.

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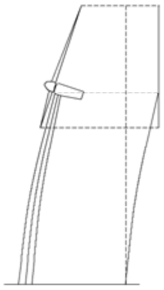

Fig.1 Wind turbine model

The maximum bending moment is calculated as following

$$M_{\max} = M \times G = M \times (1 + g\frac{\sigma_M}{M}) \tag{1}$$

where M is the mean bending moment which is decided by the mean component of wind speed, G is the gust factor which accounts for the load caused by the fluctuating component of wind speed, g is the peak factor and σ_M is the standard deviation of the load distribution. The mean bending moment and standard deviation are calculated as follow.

$$M = \int_{windturbine} \frac{1}{2}\rho C_f(r)U^2(1 + I_u^2)c(r)rdr \tag{2}$$

$$\frac{\sigma_M}{M} = \sqrt{\frac{\sigma_{M1}^2 + \sigma_{MB}^2}{M^2}} \tag{3}$$

where $\frac{1}{2}\rho C_f(r)U^2$ is the familiar expression of wind pressure , I_u is the turbulent intensity , c(r) is the characteristic size of the element at position r, σ_{M1} and σ_{MB} are resonant component and background component of wind load respectively.

THE PEAK FACTOR

In this study the peak factor is defined as the "value that a zero mean standard process up-cross once on average in a certain time T." Applying this definition into the moment based Hermite transformation method, Ishikawa (2004) has proposed the following expression for peak factor.

$$g = \kappa\left\{\sqrt{2\ln\nu_y^{'}T} + h_3(2\ln\nu_y^{'}T - 1) + h_4\left[(2\ln\nu_y^{'}T)^{\frac{3}{2}} - 3\sqrt{2\ln\nu_y^{'}T}\right]\right\} \tag{4}$$

where $h_3 = \dfrac{\alpha_3}{4 + 2\sqrt{1 + \dfrac{3(\alpha_4 - 3)}{2}}}$, $h_4 = \dfrac{\sqrt{1 + \dfrac{3(\alpha_4 - 3)}{2}} - 1}{18}$, $\kappa = \dfrac{1}{\sqrt{1 + 2h_3^2 + 6h_4^2}}$

α_3 and α_4 are third and forth order moments of the wind load. ν_y' is the zero upcrossing number in time interval T of the non-Gaussian process Y which depends on h_3, h_4 and the zero upcrossing number in time interval T of a Gaussian process which is usually written in codes.

In this study, the effect of the high order part α_4 and h_4 are neglected since α_4 is assumed to be equal to 3. The assumption gives us a simple expression of peak factor as following

$$g = \kappa\left\{\sqrt{2\ln \nu_Y^{'} T} + h_3\left(2\ln \nu_Y^{'} T - 1\right)\right\} \tag{5}$$

CALCULATING THE SKEWNESS

The problem of calculating peak factor g now becomes the problem of calculating skewness α_3 of the response. Using the method proposed by Ishikawa the following expression for α_3 is derived for the case without resonance.

$$\alpha_3 = \frac{3I_u a_{r1} + I_u^3 a_{r2}}{(K_{SMB} + K_{SMB}^{'})^{\frac{3}{2}}} \tag{6}$$

where a_{r1} and a_{r2} are integral considering spatial correlation taken on all the wind turbine area. The formula of K'_{SMB} , a_{r1} and a_{r2} can be found in Ishikawa [3)]

As discussed above, in the case of wind turbine the effect of resonance must be taken into account so in (10) the right hand part should be multipled with a factor considering the resonant component. In this study the resonance-background ratio Rd of the standard deviation is introduced. Since I_u^3 is neglectable comparing to I_u , K'_{SMB} is neglectable comparing to K_{SMB} the expression of α_3 is simplified to

$$\alpha_3 = f(Rd) \times \frac{3I_u a_{r1}}{(K_{SMB})^{\frac{3}{2}}} \tag{7}$$

In this study, the beam element model and FEM code developed by P.V. Phuc is used to analyze the response of a wind turbine model with different structural dampings. The result in fig. 2 shows that skewness and turbulent intensity has a linear relationship which confirms the correctness of formula (7). From fig. 2 it is noticed that skewness increases when damping ratio increases. And since the damping ratio of wind turbine varies in a narrow range from 0.005 to 0.01 this relation can be assumed linear. From this relation and the definition of Rd, f(Rd) is supposed to be proportional to Rd^{-2} . It is also noted that f(Rd) should become 1 where there is no resonance. Therefore the following form of f(Rd) is proposed and from the simulation results in fig.3 the safe line for different Rd of the coefficient α =1.3 is proposed.

$$f(Rd) = \frac{1}{\alpha Rd^2 + 1} \tag{8}$$

EXAMPLE

The proposed formula is used to calculate wind load on several wind turbine models of different size. Fig.4 and fig.5 are examples of how these results show good agreement with FEM simulation.

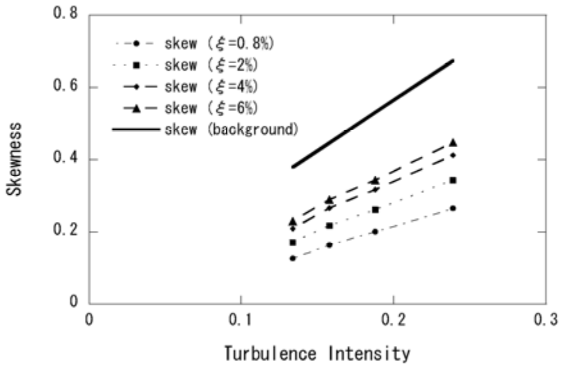

Fig.2 variation of skewness with turbulence intensity

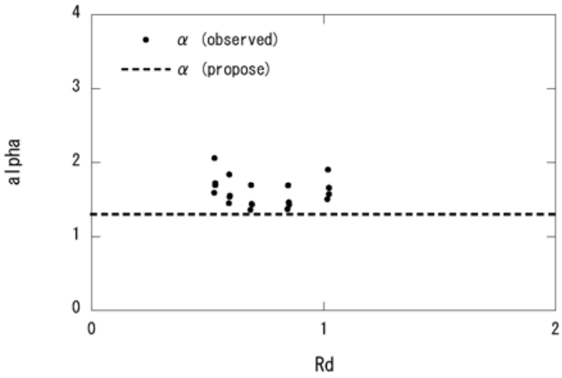

Fig. 3 The coefficient α of resonant function f(Rd)

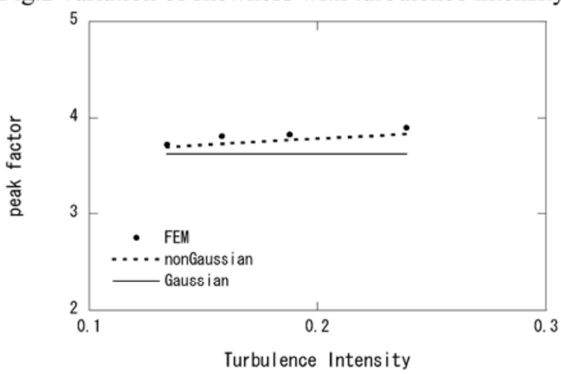

Fig. 4 Peak factor calculation result

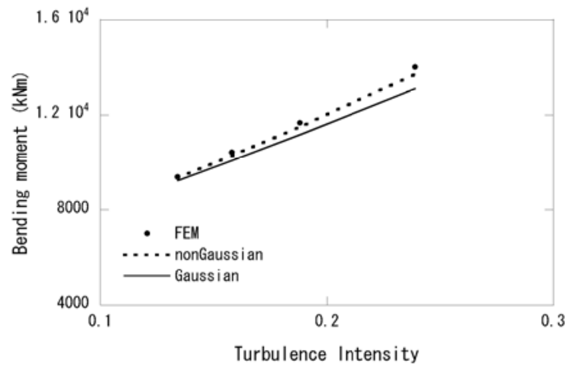

Fig.5 Bending moment calculation result

CONCLUDING REMARKS

In this study a formula for the peak factor of the non-Gaussian response of wind turbine under wind load considering both spatial correlation of wind speed and the resonant effect has been proposed. A safe line has been chosen for the coefficient α of the resonance function f(Rd) so that the formula can be applied to wind turbine of different Rd. The formula has been used to calculate wind load on wind turbine models of different sizes and Rd. The results show good agreement with FEM simulation with errors limited to the same level of the error when calculating the standard deviation (app. 3 percent).

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