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In this issue:

Assessing Long-Term Extreme Responses of Wind Turbines via Controlled Monte Carlo Simulation and Statistical Extrapolation

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Reliability- and performance-based structural design requires estimation of extreme responses with various mean recurrence intervals (MRIs). The International Electrotechnical Commission standard (IEC 61400-1 2005) recommends a load (response) extrapolation procedure to estimate the long-term (say 50 years) extreme responses of operational wind turbines from short-term (10 min) simulations. The short-term extreme turbine responses at various wind speeds are fitted with prescribed probability models, then combined with the distribution of mean wind speed for the evaluation of overall short-term extreme response distribution. Under the assumption that the short-term extremes are mutually independent, the long-term extreme responses with various MRIs are determined. For instance, the 50-year extreme response corresponds to a probability of exceedance of P_e = 3.8×10^{-7} in terms of 10 min extreme. Obviously, the estimation of long-term extremes involves quantification of extreme values with very small probabilities of exceedance. Healthcare facilities including hospitals and clinics play a critical role throughout a hurricane by providing continuity of medical care for patients admitted before a storm and serving a large number of people seeking medical treatments in its aftermath.

Previous studies have shown that the predicted extreme responses from short-term extreme value distribution are very sensitive to the probability models used in representing the sampled information. This study presents a very effective controlled Monte Carlo simulation (MCS) framework, referred to as importance splitting (ISp) or subset simulation with splitting, to simulate the large extreme responses of dynamic systems. With this framework, the extreme response of a 5MW wind turbine at operational condition is estimated as an example. The 5MW onshore baseline wind turbine model developed by National Renewable Energy Laboratory (NREL) has a hub height of 90 m and rotor diameter of 126 m. The turbine operating wind speed range is between cut-in speed of 3 m/s and cut-out speed of 25 m/s. Based on the extreme value distribution determined, the adequacy of currently used statistical extrapolation approaches is examined. The results of this study help to better predict long-term extreme responses of wind turbines.

Controlled MCS Framework

The newly proposed framework combines importance splitting (ISp) method with multivariate autoregressive (MAR) modeling of multi-correlated stochastic excitations. This ISp scheme splits a

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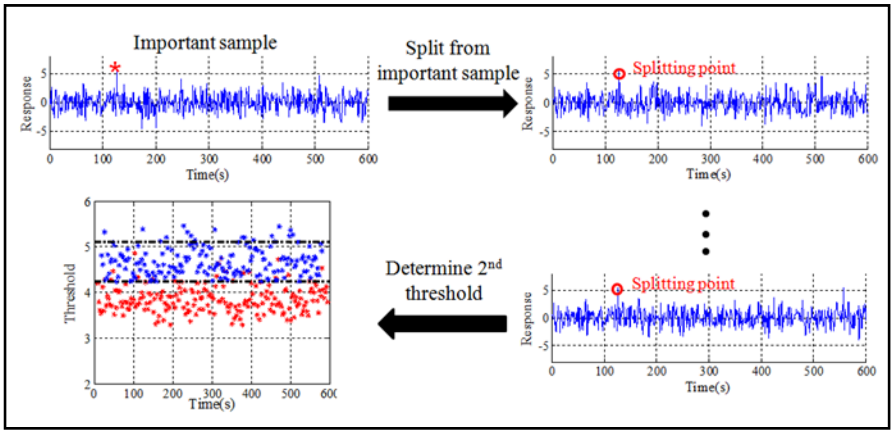

Figure 1. Determine conditional probability (or threshold) through ISp method

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small failure probability of a rare event into a set of conditional probabilities of intermediate events that can be effectively estimated through smaller number of samples. Considering the exceeding probability of a limit state response within a given time duration, i.e., $P_e = \Pr(Y > y)$, where Y is the extreme value of the limit state response, and y is a threshold level; an increasing sequence of intermediate threshold levels, $0 < y_1 < y_2 < . . . < y_m = y$, can be selected, where m is total number of threshold levels. Denote the first-passage probability at level y_i (i = 1, 2, 3, ..., m) conditional on the previous level $y_{i\text{-}1}$ as $P_i = \Pr(Y > y_i | Y > y_{i\text{-}1})$, the first-passage probabilities at different threshold levels are estimated as the product of conditional probabilities:

$$\Pr(Y > y_j) = \prod_{i=1}^{j} P_i \qquad j = 1, 2, \dots, m$$

The MAR modeling of excitations transfers the stochastic excitations as the output of a loading system with vector-valued uncorrelated white noise process as input, which facilitates an efficient generation of conditional samples with very low rejection rate. The MAR model is determined from the spectra matrix of excitations, and can be applied to various stochastic excitations. An illustration of this method is shown in Figure 1 while details are referred to Ding and Chen (2013).

The ISp scheme with MAR modeling framework enables a direct simulation of long-term extreme responses of operational wind turbines with much reduced computational efforts. For instance, to evaluate a sample of 50-year extreme response, 2,630,000 short-term samples were needed to generate one estimate when traditional MCS is used. On the other hand, a very good estimate from this scheme can be obtained by 25,600 samples for each wind speed bin, which made the simulation feasible (Ding and Chen, 2013).

Long-Term Extreme Responses by Controlled MCS and Statistical Extrapolation

The long-term extreme responses of the NREL wind turbine are predicted from both controlled MCS and statistical extrapolation methods. To implement the statistical extrapolation, the mean wind speed is divided into several wind speed bins, say 12 bins. In each bin, extremes are extracted from a limited amount (e.g., 100) of simulated short-term wind turbine responses and are fitted into a selected probability distribution model, such as Gumbel, quadratic Gumbel, lognormal, generalized extreme value (GEV) or Weibull distributions. The short-term extreme response distribution condition on wind speed, $\Pr(Y > y | V > v_i)$ is then combined with the probability of wind speed to estimate the overall short-term extreme response distribution as (IEC 61400-1 2005)

$$\Pr(Y > y) = \sum_{i=1}^{12} \Pr(Y > y | V = v_i)\, P(V = v_i)$$

In this application, the parameters of probability models are determined based on a method of moments, except that the quadratic Gumbel distribution is by curve fitting of the cumulative distribution function. The predicted results for blade root out-of-plane bending moment are displayed in Figure 2 with a comparison to the results from controlled MCS (Ding et al., 2013). It is observed that the selected probability model has a significant influence on the predictions of long-term extreme responses even it can well fit the sampled data. The difference of predicted

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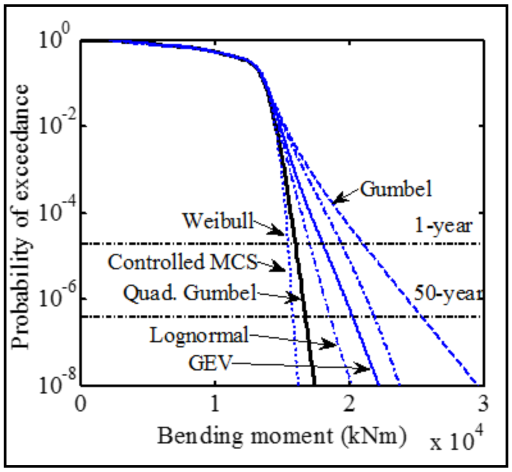

Figure 2. Overall short-term extreme value distribution

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50-year extreme responses is as large as 42%. Ding and Chen (2013) introduced the Hermite model based approach, by which the distribution model can be adaptively chosen instead of using a prescribed one, which yields a better prediction.

Conclusion

An effective framework for evaluating small failure probability of dynamic systems with multi-correlated excitations was proposed, which combines the ISp method with MAR modeling of excitations. This framework was successfully applied to the evaluation of long-term extreme responses of a utility-scale wind turbine. The adequacy of current statistical extrapolation approaches was thoroughly examined with the predictions from the controlled MCS.

References

Ding, J., and Chen, X. (2013) “Assessing small failure probability by importance splitting method and its application to wind turbine extreme response prediction.” *Engineering Structures*, 54, 180–91.

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IEC 61400-1. (2005). *Wind Turbines-Part I: Design Requirements*. Edition 3. International Electrotechnical Commission, Geneva, Switzerland.

Keynote Speakers for the 14th International Conference on Wind Engineering

The 14th International Conference on Wind Engineering (ICWE-14) will be held in the *Centro de Eventos — PUCRS* in Porto Alegre, Brazil, from June 21 to 26, 2015. So far, the following keynote speakers have been announced:

- Dr. John Holmes, JDH Consulting, Australia, “Past, present and future of structural wind engineering — with emphasis on applications
- Dr. Horia Hangan, Western University, Canada, “Novel Techniques in Wind Engineering
- Dr. Chris Letchford, Rensselaer Polytechnic Institute, USA, “Is codification of non-synoptic wind loads possible?”
- Dr. Shuyang Cao, Tongji University, China, “Towards better understanding of bridge aerodynamics”
- Dr. Elbia Silva Gannoum, ABEEólica, Brazil
- Dr. Jens Peter Molly, UL International GmbH — DEWI, Germany, “Modified wind turbine designs driven by market requirements
- Dr. Jon Galsworthy, RWDI, Canada, “Wind Engineering for Today’s Architecture: Free-Form Thinking and the Super Slender”

For all the latest information on ICWE-14, visit www.icwe14.org.

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