Uncertainty propagation through wind flow and wake loss models

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Abstract
Reducing the uncertainty associated with net produced energy prediction in a proposed wind power plant has the potential to reduce the levelized cost of energy, both by allowing more favorable project financing and by allowing more directed and robust optimization of the plant design. To this end, the development of a rigorous, quantitative framework is proposed for evaluating the uncertainties and sensitivities in energy prediction methodologies and which is appropriate for integration with existing tools and practices.

Keywords: *uncertainty quantification, operational analysis*

Introduction

At present, there is no industry-wide standard for uncertainty quantification in the preconstruction energy estimate or the post-construction operational analysis for wind plants. As the former estimate determines the financing package for a proposed wind plant development, which can contribute up to almost 20% of the capital expenditures for a project [1], there is significant fiscal advantage to reducing uncertainty in the estimate. The latter analysis also has significant potential to help identify where pre-construction energy estimates introduce inaccuracy and imprecision in comparison to realized performances. Thus there is exists strong motivation to develop and integrate into standard industry practice a rigorous uncertainty quantification methodology in both of these contexts.

An end-to-end methodology for uncertainty quantification and sensitivity analysis of the energy estimation process may be broken down into three component methodologies: 1) Identification and quantification of input parameter uncertainties, 2) Propagation of the input parameter uncertainties and sensitivity analysis of the models, and 3) Characterization of uncertainties introduced by model assumptions and simplifications. Although treated separately, it is emphasized that the three component methodologies are interconnected and the development of an appropriate end-to-end methodology will be iterative between the three.

In this presentation, focus is placed on the first and second methodologies, namely considering the propagation method of measurement and parameter uncertainties through the operational analysis process.

Methods

Uncertainties associated with the input parameters may be categorized as type A or type B. Type A uncertainty refers to variations for which a statistical description is possible; for example the natural variation in wind speed. Type B uncertainties are those that cannot be described by purely statistical means; for example, the inability to capture certain physics when using an empirical model for wind speed extrapolation may be assigned an uncertainty range by expert opinion.

In the context of operational assessments, measurement uncertainties arise from a large range of sources: the data available for analysis typically includes environmental measurements from each of the meteorological towers, SCADA measurements from each of the turbines, and metered data at the point of interconnect (i.e. plant-wide), all reported at intervals of 10 minutes or greater. These data are supplemented by monthly-averaged grid curtailment for the plant during the time frame of operation and hourly-averaged MERRA-derived windspeed and density data.

For the present analysis, the 10-minute mean and standard deviation of the windspeed, wind direction, temperature, and barometric pressure measurements were taken from each of the meteorological towers. From each of the turbines' SCADA data, the measurements considered include mean nacelle windspeed, power transmission, nacelle position, and pitch of the first blade. Following the IEC-61400-12-1 standard, the measurement uncertainties were modeled as normal distributions from the reported means, with the standard deviations modeled as root-mean-square combinations of the uncertainty sources. Contributions to the net standard deviation of a measurement varied according to the measurement type (wind speed, temperature, etc.), but in general included at least calibration error, data acquisition resolution, mounting influences, and (in the case of the standard deviation over the 10 minute averaging interval being reported) statistical variation. Again, this analysis was conducted at each 10-minute time interval, in order to uniquely model the uncertainty for each measurement in the time series.

To propagate these uncertainties through the operational analysis, each measurement was sampled from its distribution in order to create a replicate time series of operational data. The full operational analysis was then conducted on each of these replicate data sets and the variation between data sets evaluated. Given the computational intensity of the operational analysis process, only a minimal number of replications have to date been considered. However, from the initial results, it would appear that for the determination of plant-wide operational metrics, input uncertainties play are the source of relatively negligible variation.

Momentarily neglecting these type A measurement uncertainties, the next stage in understanding the uncertainties within the energy estimation process is to model the uncertainty introduced by the analysis methods themselves. For example, it is necessary to filter the data being used in the analysis prior to analysis and these filters operate using parameters selected by analyst. In order to propagate these type B sources of uncertainty through the operational analysis, a reasonable range of values for each parameter was determined. The operational analysis was again then repeated multiple times, using parameters drawn from the assigned ranges, assuming uniform distributions.

Future work

Having obtained preliminary understandings of the propagation of measurement and parameter uncertainties through the operational analysis method, it remains to quantify the uncertainty introduced by the operational analysis method itself. (For example, what filters are applied to the data, what models are used to provide the necessary extrapolations or interpolations of the data, etc.) Examination and comparison between several representative methodologies will comprise the third stage of this uncertainty quantification exploration, after which the results of the stages will be combined into a rigorous and comprehensive uncertainty quantification framework. In order to make this framework less computationally intensive, it is proposed to use a nested implementation of the Dempster-Shafer evidence theory to propagate the type B uncertainties and a stochastic collocation surrogate model to propagate the type A uncertainties.

References

1. Moné, C., Stehly, T., Maples, B., and Settle, E., 2015. 2014 Cost Of Wind Energy Review. Tech. Rep. NREL/TP-6A20-64281, National Renewable Energy Laboratory, October.

2. Clifton, A., Smith, A., and Fields, M., 2016. Wind plant preconstruction energy estimates: Current practice and opportunities. Tech. Rep. NREL/TP-5000-64735, National Renewable Energy Laboratory, April.