Wind Plant Layout Optimization

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ABSTRACT

Nordex/Acciona Windpower presents a methodology to reduce levelized cost of energy (LCOE) for wind generation by improving the wind turbine siting process. By linking load models, balance of plant (BOP) models and wind models in one loop with optimization algorithms, layout designers can select the best turbine types and operating modes, utilize the maximum potential of wind turbines while avoiding excessive loads, and comply with transport and grid requirements at the lowest cost. Project examples comparing baseline layout designs with optimized designs show the potential to optimize turbine type selection, reduce the total number of turbines deployed, achieve higher net energy production, reduce BoP costs, and reduce overall turbine component loads.

Index Terms: *Wind Power Generation; Cost Optimization; Micrositing; Layout; Balance of Plant.*

EXECUTIVE SUMMARY

Nordex/Acciona Windpower is currently engaged in research and practical tests to quantify the potential to reduce the levelized cost of energy (LCOE) by improving the wind turbine siting process. Three primary opportunities have been identified which represent potential for LCOE reduction. This report outlines our methodology to address these three areas, highlighting a path to LCOE improvement for the wind energy sector.

The first opportunity involves selecting the best turbine types and operating modes from a range of available options. The base turbine type is often determined at the beginning of the siting process based on measured or modeled wind conditions and an initial turbine layout is designed.

As alternative layouts are compared, the layout designer would benefit from the ability to evaluate alternative turbine types in an iterative process to find the best result.

The second opportunity involves applying a fast and precise load modelling method to layout alternatives. Given the ability to quickly apply a load model to many alternatives, overly conservative or aggressive siting decisions can be avoided. As a result, load mitigation strategies such as wind sector and wind velocity management [1] [2] can be objectively compared to select a layout which utilizes the maximum potential of the turbine while avoiding excessive overload.

A third opportunity is related to transport roads, crane platforms, medium voltage and high voltage grid design. While turbine suppliers provide transport requirements and specifications related to grid compliance prior to initial turbine siting, these specifications are normally checked manually and only evaluated for a small number of layout alternatives. With a direct link to electrical models, specialized transport information, and balance of plant (BOP) models layout alternatives can be objectively compared based on approximate unit costs and locate turbines in positions with the best combination of high production and low costs which still comply with transport and grid requirements.

Optimal siting decisions with regard to levelized cost of energy require information from the customer and the turbine manufacturer in all of these areas to be closely linked in one loop for fast comparison of alternatives. Nordex/Acciona Windpower has linked internal mechanical and electrical models with a wind flow model, a BOP cost model, spatial information, and other specifications provided by customers. The resulting toolchain exchanges data from all necessary models to evaluate the levelized cost of energy, structural integrity, and grid compliance of many turbine types and locations for a given site.

Practical tests demonstrate that closing the information gap in these three areas and using an iterative optimization algorithm can reduce LCOE. This result highlights the value of early collaboration between project developers and turbine manufacturers, establishing a direct link to load models and BoP models during layout design.

METHODOLOGY

Opportunities to improve siting decisions have been evaluated by selecting test sites with baseline layout designs, establishing a process linking all required models and input data, using the process to design new layouts, and comparing LCOE of the new layouts to baseline.

This linked optimization process is a combination of commercial and internally developed tools. Wind flow conditions have been modeled using WindPro and the Nordex/Acciona Windpower Site Assessment Tool (SAT) [3]. Mechanical loads have been modeled using the certified Fast Load Approximation (FLAp) model integrated into SAT. Grid code suitability has been modeled by the internally developed Nordex/Acciona Windpower Grid Compliance Tool. BOP costs have been modeled using Openwind Enterprise [4]. Three optimization algorithms have been used within the process, a genetic algorithm-based turbine type optimizer integrated into SAT [5] [6] [7], a layout optimizer under development as an extension to SAT, and the layout optimizer integrated into Openwind. While the linked optimization process calculates LCOE, an independent internal pro forma financial model has been used to verify the performance of the linked optimization process.

Two practical tests have been completed including a full independent LCOE comparison, one in mountainous terrain in the Americas and one in hilly terrain in Europe. In both cases an initial layout has been created by a project developer with BoP considerations and costs evaluated in detail. The linked optimization process discussed above has been completed in order to determine the potential for improvement in LCOE.

The test in the Americas consists of one baseline layout (Baseline A) and one optimized layout (Optimization A) in which turbines can be located anywhere within a large area. The test in Europe represents the potential for improvement in a more constrained scenario (Optimization B) allowing very limited changes to initial turbine positions (Baseline B) to stay within the bounds of existing permitting.

RESULTS AND DISCUSSION

The manually created layout Baseline A consists of a combination of Acciona AW 116 and AW 125 wind turbines to account for the variation in wind conditions across the site. Optimization A shown in Figure 1 has produced a layout design using only Acciona AW125 wind turbines, reducing the total number of turbines while maintaining a higher net energy production. Net AEP has increased significantly with only a slight increase in costs. Total length of BOP has been reduced, but overall costs increased slightly due to placement of turbines in an area with steeper slopes and away from an existing road. Some areas in which turbines were originally planned have been identified as unacceptable for loads, and new areas have been selected resulting in an overall reduction in loads. Comparison of modeled results shows an overall reduction in LCOE of 9.7%. The quantity of reduction in LCOE is highly dependent on several factors including the quality of the original layout design, degree of variability in wind conditions, degree of variability in BOP costs, and the relative complexity of other site restrictions. This site represents a high degree of variability and complexity, and therefore despite a state-of-the-art initial layout design shows significant potential for improvement when loads are considered.

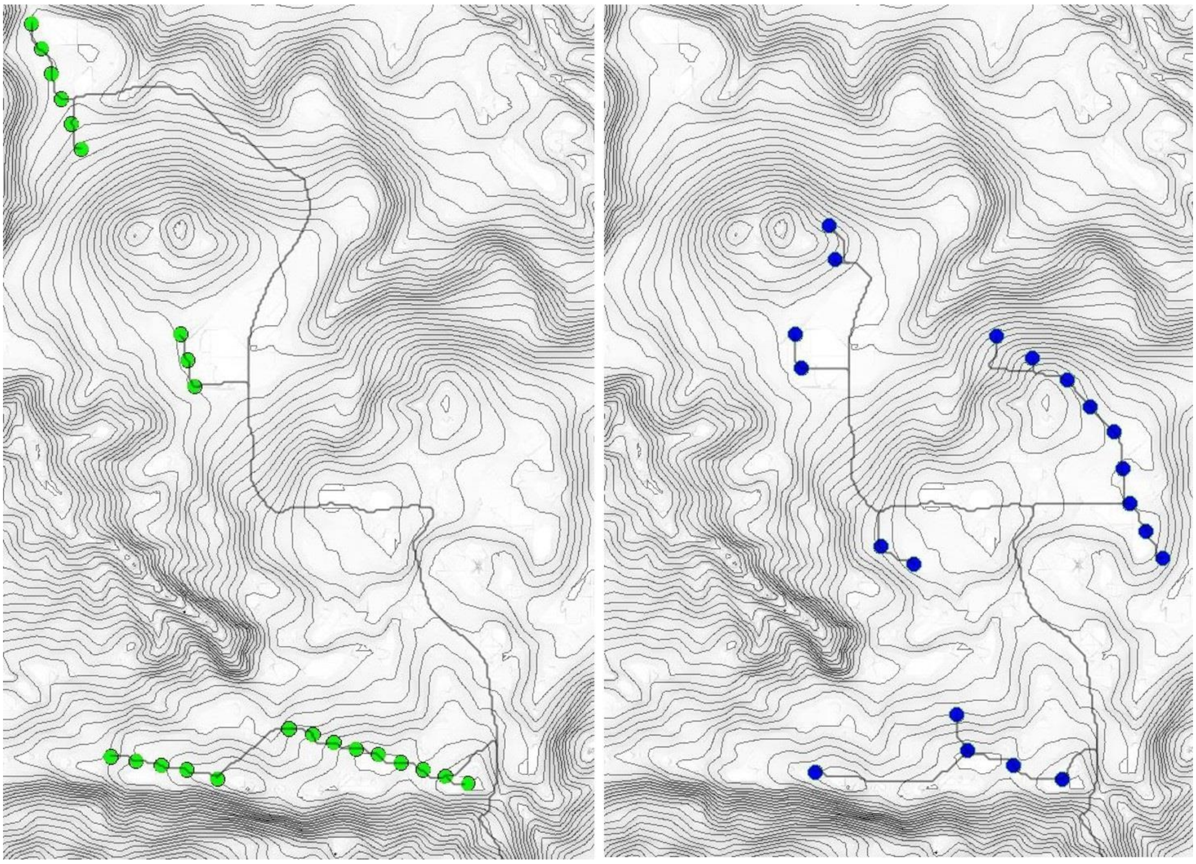

Figure 1: Baseline A (left) and Optimization A (right)

Baseline B consists of Nordex N117 wind turbines. Optimization B1 shown in Figure 2 has produced a layout design with turbines spaced slightly closer together, allowing placement at higher elevations on average and a more efficient BOP network. Optimization B1 has a resulting increase in AEP and a reduction in BOP costs, with a total reduction in LCOE of 1.0%. While this is a significant improvement, the quantity of reduction in LCOE is relatively low for this site because the potential change to turbine positions was very limited by permit requirements.

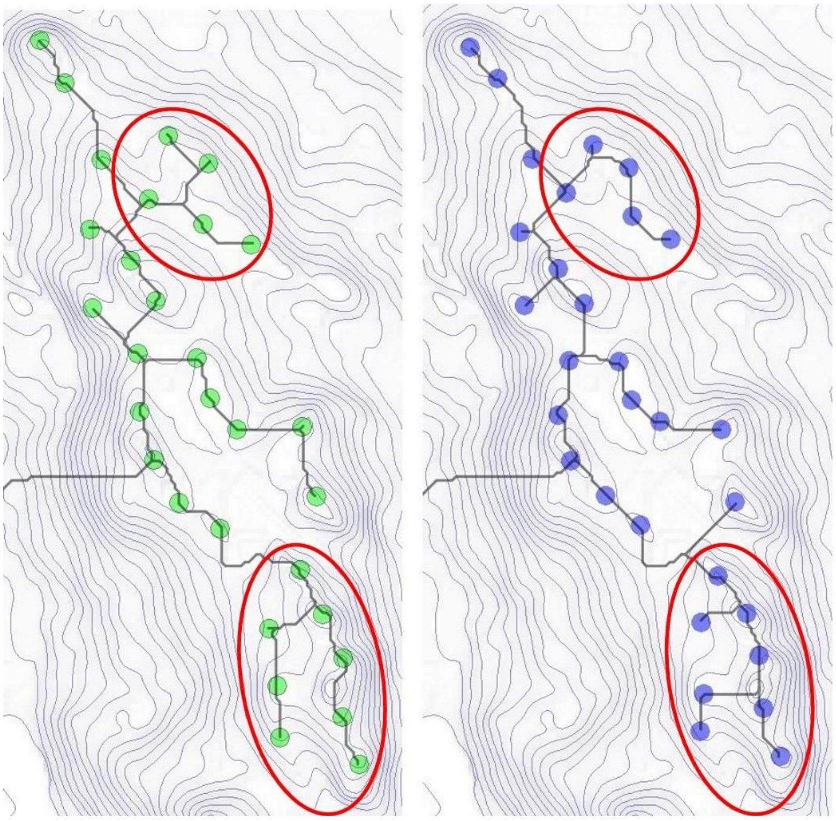

Figure 2: Baseline B (left) and Optimization B (right)

CONCLUSIONS

Nordex/Acciona Windpower project tests have demonstrated that significant LCOE reductions are possible when information from project developers and the turbine manufacturer is closely linked in one loop for fast comparison of alternatives with optimization algorithms. Early collaboration between turbine manufacturers and their customers is necessary to establish a direct link to load models and BoP models during layout design and enable reductions in LCOE by optimizing turbine siting decisions.

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BIOGRAPHY

Zachary Parker received a Bachelor of Science degree in mechanical engineering from Boise State University in 2009.

He has been active in the wind energy sector since 2008 beginning as a Research Assistant with the US Department of Energy Wind for Schools program. From 2009 to 2012 he was involved in utility scale wind energy project development and site assessment for both Gamesa and Nordex. From 2012 to 2015 he conducted research at the National Renewable Energy Laboratory (NREL) in offshore wind energy development, wind energy assessments in emerging markets and wind turbine test apparatus and procedures. He has been conducting research and development for Nordex/Acciona Windpower in the Hamburg office since 2015 in the "Applications Concepts and Methods" (ACM) group in the area of wind plant optimization, collaborating in the Smart Windfarms research initiative along with Fraunhofer IWES.

Matthias Dehn majored in physics from the University of Hamburg, Germany, in 2003 and received a Ph.D. degree in physics from the same university in 2007.

From 2008 to 2011, he was active in the New Zealand wind industry as a wind energy project developer, wind data analyst and consultant. He has been conducting research and development for Nordex/Acciona Windpower in the Hamburg office since 2011 in the “Applications Concepts and Methods” (ACM) group. His focus is the improvement of the turbine siting process through development and implementation of capable software tools. He is researching the effects of wind conditions on turbine components as well as methods of optimizing the wind park configuration for a beneficial cost structure as part of the Smart Windfarms collaboration with Fraunhofer IWES.

Carolina Marques received a Bachelor's degree in science and technology from the Federal University of ABC, Santo André in 2012 and a degree in energy engineering from the same university in 2015.

From 2013 to 2014 she was an exchange student at the University of Sydney, Australia. In 2015 she joined the Engineering Department at Nordex/Acciona Windpower, Brazil as a Wind Resource Engineer. During that year she spent 3 months in Ciudad de la Innovación, Pamplona attending a site assessment training with fellow members of the Wind and Site Department of Acciona Windpower. Her research interests include renewable energy technologies, optimization of wind power plants, fluid dynamics and energy efficiency.