Dynamic Line Ratings and Wind Farm Predictions via Coupled Computational Fluid Dynamics and Weather Data

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Abstract

The maximum capacity of transmissions lines is traditionally calculated using static ratings of the conductor using predetermined environmental conditions assuming little wind. The use of computational fluid dynamics (CFD) simulations coupled with weather stations data can potentially be used to give more accurate predictions of maximum capacities, which are typically underestimated. The application of this method can allow for the expansion of addition of new wind farms for electricity supply due to the synergistic relationship that exists; as more wind is present to generate power, it adds additional convective cooling to a line increasing the capacity.

Method

The process for developing an accurate CFD model relies on first constructing the appropriate mesh and boundary conditions. The terrain elevation is constructed from data that is mapped from a latitude-longitude space into a linear projection to allow for the easy use of a Cartesian grid in the CFD. The spatial resolution used here consists of 30 meter increments in the horizontal directions, over an area approximately 10 by 20 kilometers. To account for the sub-grid effects near the surface, a roughness factor is determined which accounts for trees, shrubs, buildings and so forth. The elevation and roughness layer of the domain is shown in Figure 1.

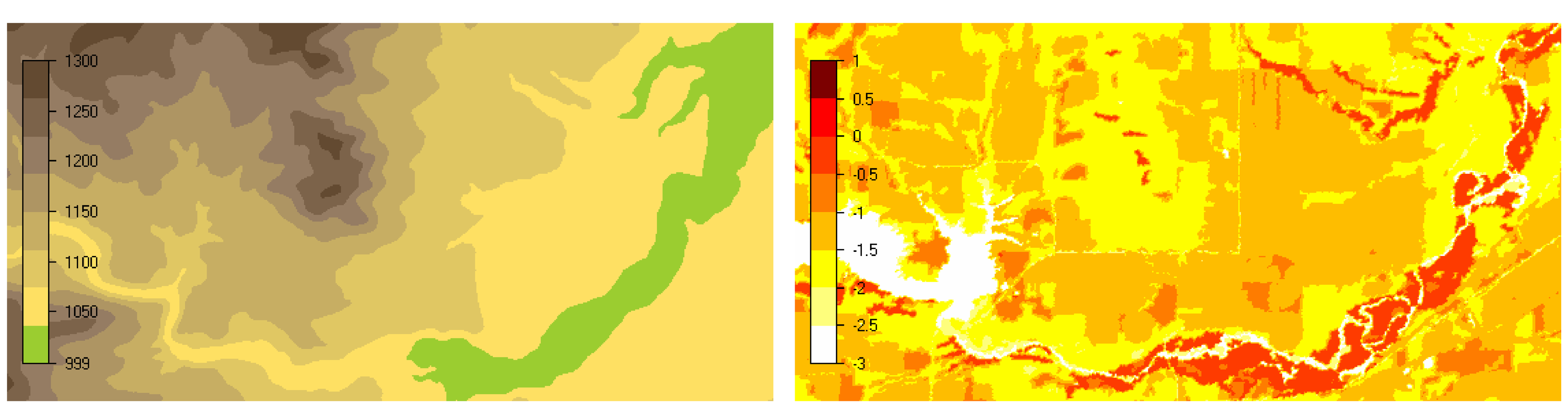

Fig. 1: Terrain elevation and logarithm of roughness for the area of interest.

A grid for this region is constructed with the same 30 meter spacing as the elevation data, and with a non-uniform vertical grid with 5 meter resolution near the ground level, 10 meter resolution up to 100 meters, followed by stretched spacing up to 3500 meters. The mesh for the horizontal and vertical domain is shown in Figure 2. The domain contains a total of 9.5 million cells. The CFD code solves the Reynolds-averaged Navier Stokes (RANS) equations using the standard *k*-ε RANS model for turbulent kinetic energy and dissipation rate. The code is run in parallel on 8 CPUs for 12 different incoming wind sectors, each corresponding to a different CFD simulation, equally spaced by 30 degrees.

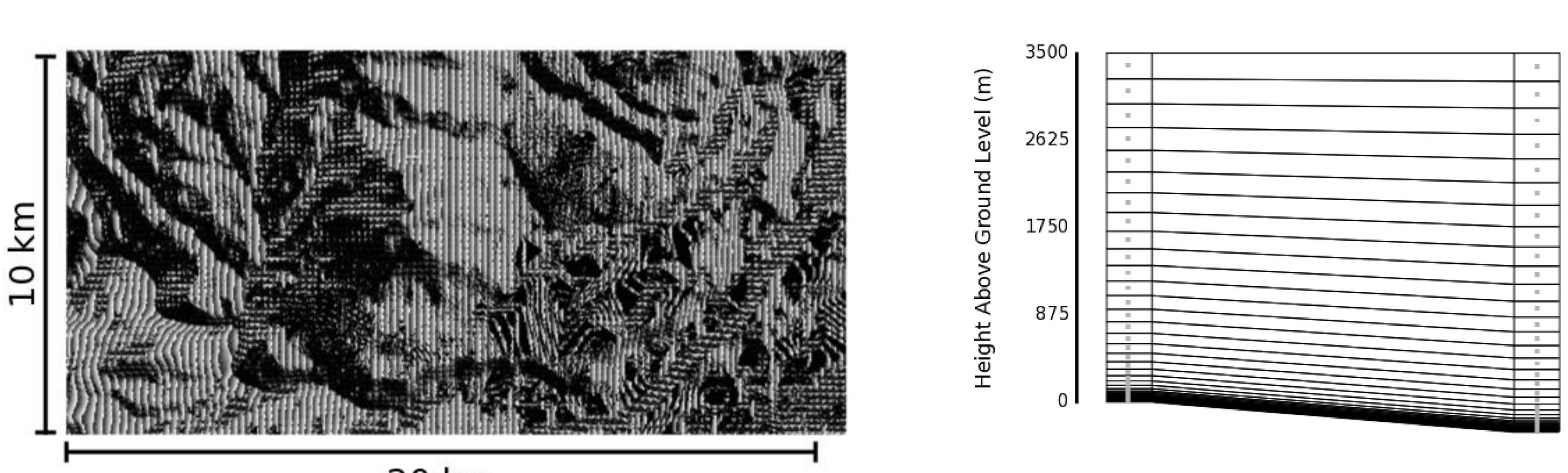

Fig. 2: Mesh of the x-y plane and the vertical grid spacing.

For the region of interest there is a small subsection of the power lines that the simulation is focused around, the midpoints of the power line structures are shown with squares in Figure 3. The weather stations that have been installed to monitor the system are shown with circles at the ends of the "T" and at the intersection. A proposed wind farm location is shown north of the currently installed power lines with triangles on the ridge.

Fig. 3: Locations of power lines (squares), weather stations (circles) and proposed wind farm (triangles) in the region.

Results

The results of the simulations are extracted at 10 meters above ground level, the height of the power line midpoints and weather stations, and at 80 meters, the height of the turbines. The wind field vectors at 10 meters above ground level for the main 270° incoming sector are shown in Figure 4. The WindSim code uses data from the nearby weather stations to find scaled values for wind direction changes and speed ups for each of the midpoint locations for every incoming wind sector and stores this in a tabular form that is used by INL's general line ampacity state solver (GLASS).

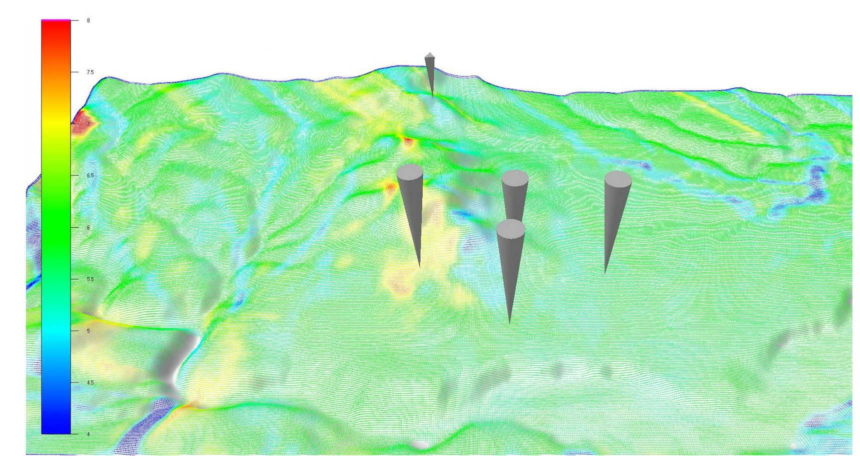

Fig. 4: Wind vector field for the 270° incoming sector with weather stations and terrain.

In addition to providing individual scaled results in the form of the lookup tables for the GLASS code, the full domain of interest can be appropriately weighted based on the proximity to the weather stations. The weighted values for two of the four weather stations are shown in Figure 5.

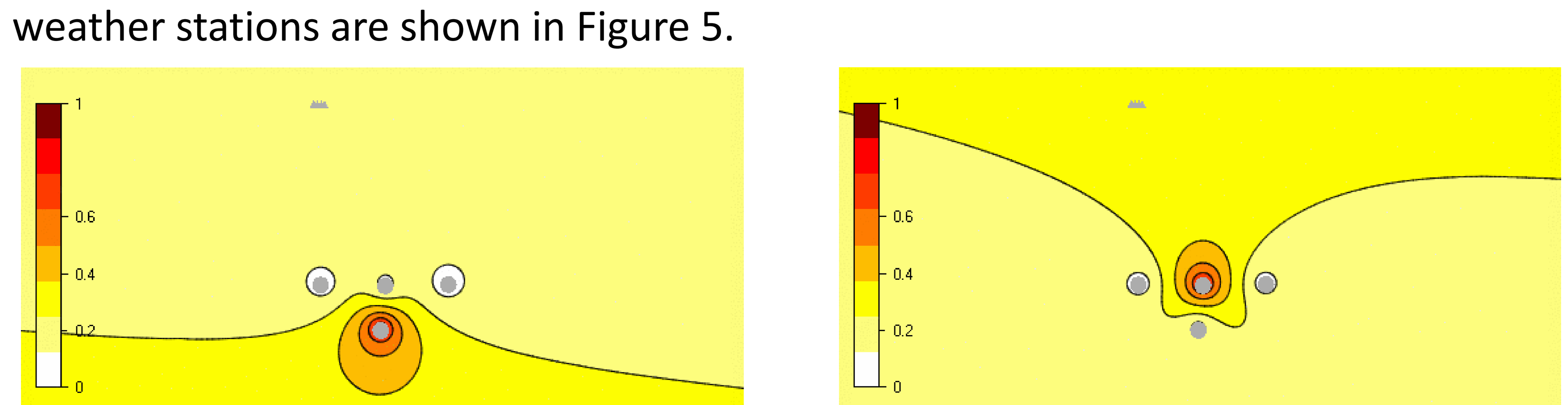

Fig. 5: Weighting parameters for two of the region's weather stations.

The conglomerated results from the weighting procedure can be used to produce a climate weighted wind speed plot, which can consequently produce a power density plot for the region. This plot for the power density is shown in Figure 6. The location for the proposed wind farm on the ridge shows an estimated power density about 6000 W/m^2, as opposed to 3500-4000 W/m^2 in the flat areas of the region.

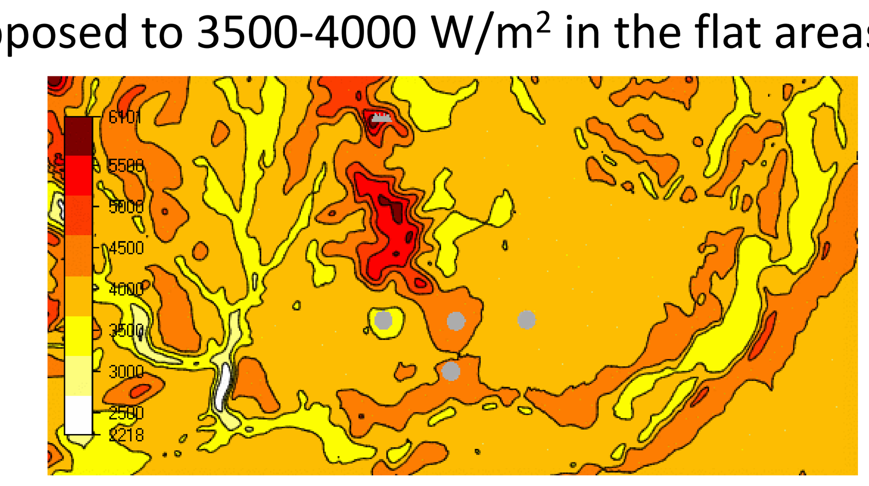

Fig. 6: Climate weighted power density.

GLASS is software developed at INL to process realtime weather data and calculate weather based ampacity ratings and line temperature estimates with the IEEE 738 standard informed by CFD model. Specifically, when using the GLASS code for each midpoint location, dynamic line rating (DLR) ampacity increases of 20-60% are typical. An example of possible increase in ampacity normalized to a static rating based on conservative weather condition assumptions is shown in Figure 7. DLR can have significant impact on wind integration and utility operations. This technique has potential to significantly improve DLR because the CFD data has much more resolution than other methods being attempted.

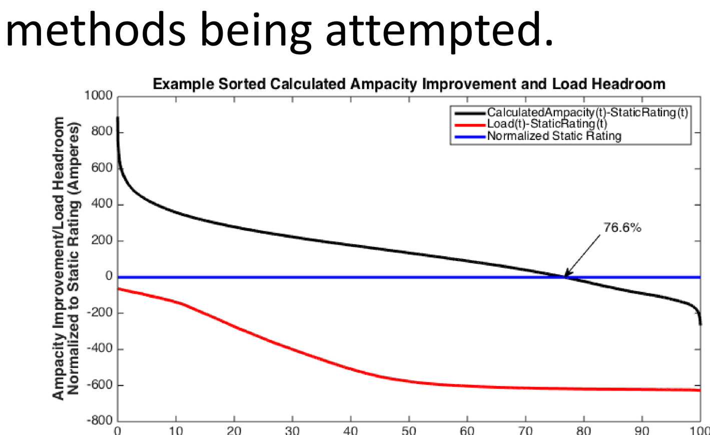

Fig. 7: Example of ampacity increase over static rating, DLR (black), static (blue), load (red).

Conclusions

Idaho National Laboratory has performed CFD calculations coupled with field weather data to provide wind field predictions that can be used to calculate dynamic line rating ampacity increases. In addition, the CFD calculations have been used to estimate power density of turbines in a region of interest.

- J. Gentle, K. Myers, J. Bush, S. Carnohan and M. West, "Dynamic Line Rating: Research and Policy Evaluation," PES General Meeting, pp. 1.5, 27-31, 2014 IEEE.
- J. Gentle, W. Parsons, M. West, and S. Jaison, "Modernizing An Aging Infrastructure Through Real-Time Transmission Monitoring," PES General Meeting, 2015 IEEE