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

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(note: 1500 words max, section names are from the abstract requirement page, make PDF to submit)

1. Introduction

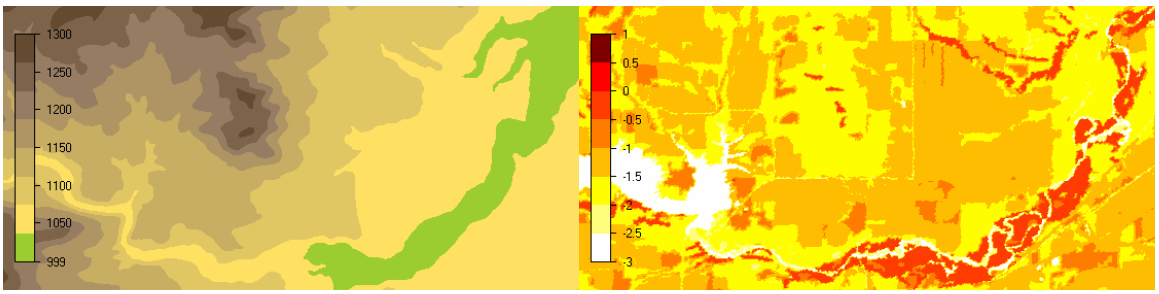
The overall goal is to couple the field data obtained with weather stations with computational fluid dynamics (CFD) simulations such that real-time predictions can be made on line ampacity ratings, and for the same results to be applied to predict power output for wind farms in the region. The method has shown potential based on past results[i,ii], and this study completes a collaborative effort to use the coupling of CFD and historical data for a specific industry case study. As many power lines are operated using static ratings with appropriate engineering estimates, there exists potential to further optimize the capacity using such models. The application of this method would be in the expansion or addition of new wind farms for additional electricity supply due to the synergistic relationship that exists; as more wind is present for power, it adds additional convective cooling to a line, potentially increasing the line capacity.

2. Approach

Within this region there are four weather stations that have collected data over the course of several months placed at strategic locations along the power line grid. In this region, the CFD software is utilized for predictions of the full wind fields. Lookup tables for each of the midpoints between the power line structures are created. These lookup tables require the incoming direction and speed of the wind, and will output the altered wind speed direction and speed up/slow down at each of the midpoints. This data can then be used in combination with software developed at INL to give accurate predications of line ampacity ratings. In addition, the scaled results of the CFD simulations can be used to predict power output for additional wind farms in the region.

3. Body

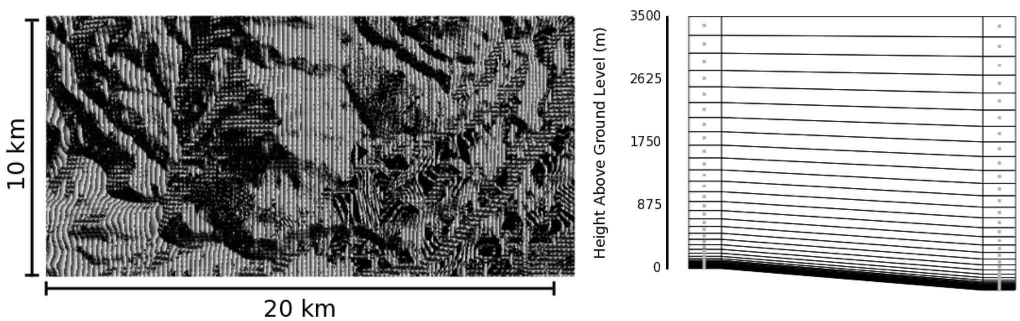
The WindSim software is utilized for the CFD simulations in this study. This software requires the use of a Cartesian grid for convergence of the CFD solution, and as such the region must be mapped from a latitude-longitude space into a linear projection. Prior to running the CFD simulations, the terrain for this region is built using a spatial resolution of the elevation in 30-meter increments to mesh large topographic features affecting the wind flow. In addition, vegetation maps are used to construct data on normalized roughness values to overlay on this region. The surface roughness of the model is built to account for terrain effects that are smaller than the grid, such as trees, shrubs and buildings. The overall span for the region of the simulations is approximately 10 km in the north-south direction and 20 km in the east-west direction. The terrain elevation and log of the roughness are shown in Figures 1a and 1b, respectively.



(a) (b)

Figure 1. The terrain elevation of the region (a), and the log of the roughness layer (b).

In the WindSim software, a constantly spaced Cartesian mesh is used for x-y space with 30-meter spacing. For the vertical direction, a 5-meter resolution is used up to 50 meters to resolve the boundary layer near the ground more accurately, followed by a 10-meter resolution up to 100 meters, then a pseudo-logarithmic space is used up to 3500 meters above ground level. The domain of the CFD simulation contains about 9.5 million cells. The x-y mesh of the domain is shown in Figure 2a, and the z direction spacing is shown in Figure 2b.



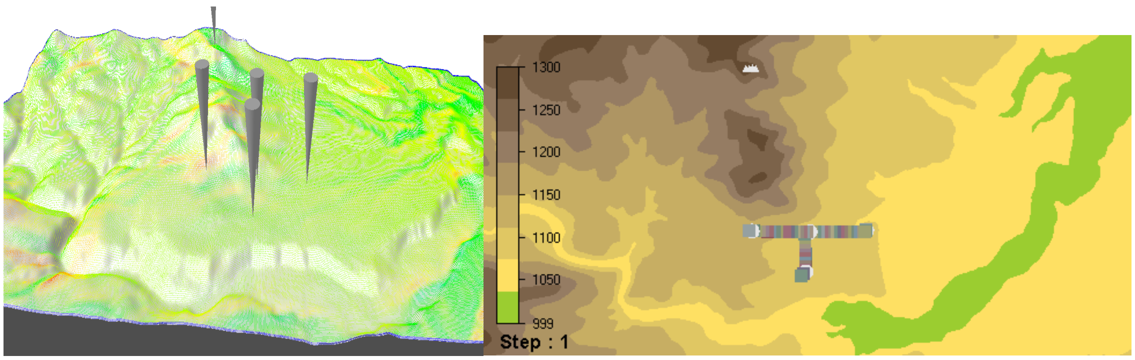
(a) (b)

Figure 2. Mesh of the x-y plane (a) and the representation of the vertical mesh spacing (b).

The CFD code solves the Reynolds-averaged Navier-Stokes (RANS) equations to model the turbulence. The standard *k*-ε RANS model is used here, which includes transport equations for the turbulent kinetic energy, *k*, and the dissipation rate, ε.

The incoming wind speed is taken to be 10 m/s for the CFD results, but this is scaled for the climatology data taken from the weather stations in post-processing steps.

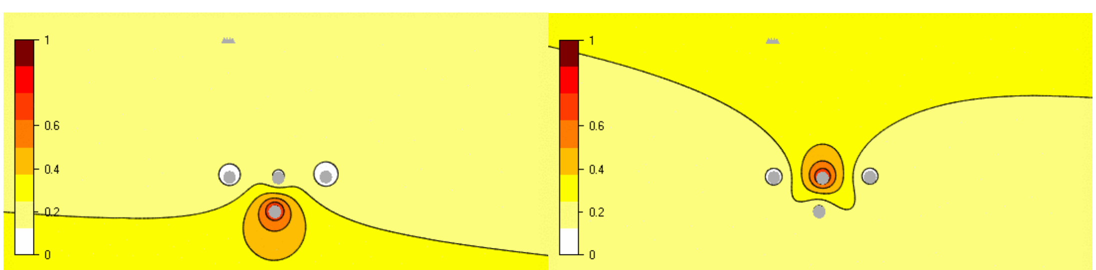
The CFD simulation is run in parallel on 8 CPUs for 12 different incoming wind sectors with 30 degree spacing between each. Each of the wind sectors is computed as a different CFD simulation by altering the domain boundary conditions. The wind speed vectors for one of the wind sectors are shown in Figure 3a. Objects are placed in the CFD code to represent each of the midpoint locations along the power line. The square points in Figure 3b represent each of the midpoints in the segments of the power lines that are investigated here. For midpoint calculations, the data from the closest weather station – shown in circles – is used as reference.



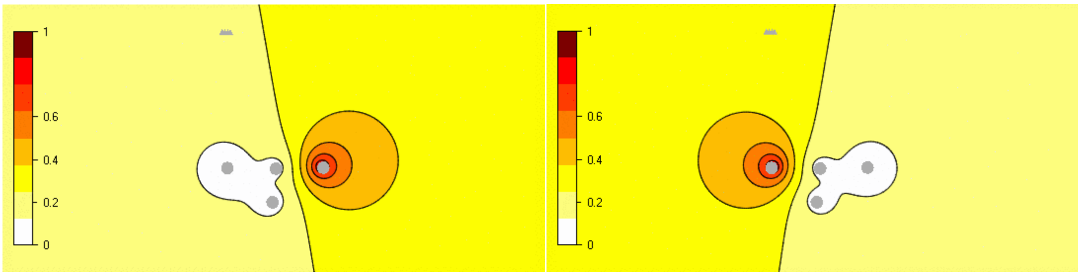
(a) (b)

Figure 3. Wind speed vectors overlaid on the terrain for one of the sector solutions (a), and the locations of all midpoints along the power line segments (b).

The WindSim code can be used to appropriately scale the results of the CFD simulations by the nearby weather stations for the entire domain of interest. The weightings of the four weather stations in the region are shown in Figure 4. In the area near weather stations, the data is weighted very highly to the nearest station, but further away the weather stations are weighted more equally.



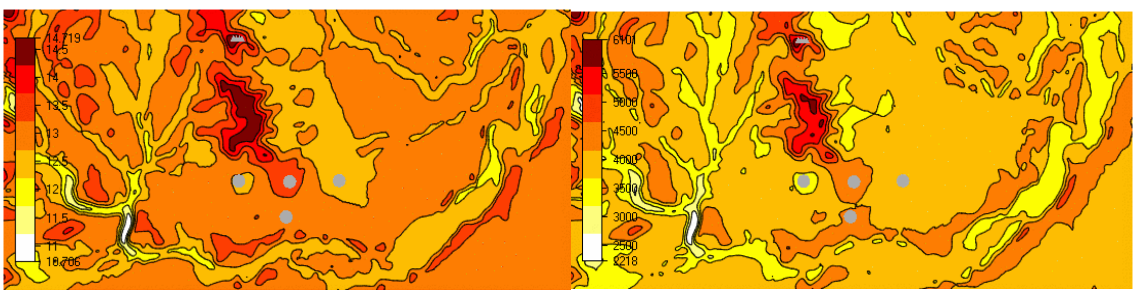
(a) (b)



(c) (d)

Figure 4. Weighting parameters of the region for the four weather stations: (a) WS3 (b) WS14 (c) WS32 and (d) WS49.

With the weighting of these four weather stations, then a climatology-based prediction on the wind speed can be made for the entire region. The wind speed for the north vector is shown in Figure 5a. With these wind speed values, a power density plot for the entire region can then be calculated; this is shown in Figure 5b, along with triangles to represent a proposed wind farm location. This proposed location is on an undeveloped ridge with higher than normal wind speeds for the region, and some of the highest power densities. The estimates for the ridge are about 6000 W/m^2 compared to 3500-4000 W/m^2 in the flat regions.



(a) (b)

Figure 5. Climate-weighted wind speed plot (a) and corresponding power density plot (b) of the region.

For the calculations of the dynamic line ratings, several additional factors are taken into account. The type of the conductor of the line determines its heat transfer parameters such as emissivity, thermal conductivity and the surface area size. The current capacity can be calculated from the combination of the convective heat loss (from the CFD), the radiative heat loss (based on ambient temperature and emissivity properties), and the heat gain from the sun (from local measurements). The static line ratings that are normally used are based on fixed values for the seasonal temperature and wind speeds [iii].

4. Conclusion

Results for using the WindSim CFD code to predict windfield simulations has been coupled with field data taken from local weather stations to provide accurately scaled predictions over a large region of interest. These results have been used to show that the dynamic capacity of the studied power line in the region can be increased beyond the static estimate approach.

5. Learning Objectives

Through completing this research, we are seeking to combine the temporal data obtained through field measurements with large data obtained with CFD simulations to provide predictions of dynamic line ampacity ratings. Through successful application in this test bed, the technique will provide the ability to potentially increase the line ratings as needed based on local wind and weather conditions, or provide the expansion of wind farms without the potential need for construction of additional power lines, dependent on the conditions and size of expansion.

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[i] Greenwood, D.M., Gentle, J.P., Myers, K.S., Davison, P.J., West, I.J., Bush, J.W., Ingram, G.L. and Troffaes, M., 2014. "A comparison of real-time thermal rating systems in the US and the UK." *Power Delivery, IEEE Transactions on*, *29*(4), pp.1849-1858.
[ii] J. P. Gentle, K. S. Meyers, T. Baldwin, I. J. West, K. Hart, B. Savage, M. Ellis, and P. Anderson, "Concurrent wind cooling in power transmission lines," presented at the Western Energy Policy Res. Conf., Boise, ID, USA, 2012.
[iii] *Standard for Calculating the Current-Temperature Relationship of Bare Overhead Line Conductors*, IEEE Standard 738, 2013.