Dynamic Line Ratings Predicted with Computational Fluid Dynamics Simulations in Complex Terrain

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1. Introduction

The overall goal of the study is to couple the field data obtained from weather stations and computational fluid dynamics (CFD) simulations with current weather data such that accurate estimations of real-time overhead transmission line ratings (ampacity) can be made. While the method has shown potential based on past results[i,ii], this study applies the method to an area with extremely complex terrain for the first time. This extremely complex area of study is Hell's Canyon, the deepest river gorge in North America, located along the border of Idaho and Oregon. The Snake River flows more than 1600 meters below the canyon's west rim, and 2300 meters below the mountain peaks to the east. Due to the hydroelectric dams in the region, electric transmission lines exist to connect the gorge generation to populated regions. Accurate estimation of wind speed and direction at every transmission line span, the midpoint between transmission structures, in this complex of terrain is challenging, but this methodology attempts to accurately resolve the challenges.

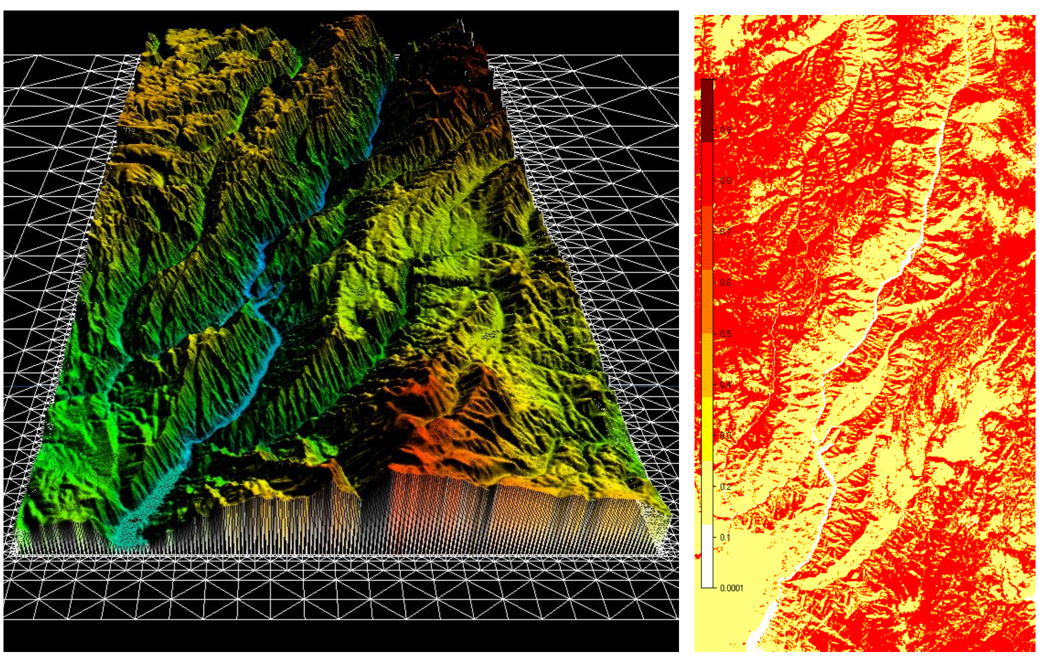
2. Approach

Within this region, there are six weather stations that have collected data over the course of several months placed at strategic locations along a power line in the area. In this region the WindSim CFD software is utilized for predictions of the wind fields. This software was originally designed for use in wind power generation, and it is being utilized for a new use here. Due to the size of the region, the area is split into multiple simulations that are then coupled together using the Wind Atlas method that has been recently developed. The combined data from the simulations are used to create lookup tables for each of the midpoints between the power line structures. These lookup tables require the incoming wind speed and direction from each real time weather station, and will output the transferred wind speed and wind direction through speed ups or slow downs and direction shifts of plus or minus a CFD informed value for each span's midpoint. This allows for a computationally efficient model (CEM) to estimate wind speed and direction at each transmission line span when real time data is provided via a limited number of weather stations.

This data can then be used in combination with the General Line Ampacity State Solver (GLASS) software developed by INL, which implements the IEEE 738 overhead transmission line rating in combination with CEM to give accurate predictions of line ampacity ratings.

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; therefore, the region must be mapped from a latitude-longitude space into a linear projection. For this data set, transformation into the UTM 11 projection was used. Prior to running the CFD simulations, the terrain for the region of interest around Hell's Canyon 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 about 30 km east-west and 60 km north-south. The map of the terrain elevation was created with global mapper and is shown in Figure 1a. This highlights the large elevation changes in the terrain from the mountains into the river gorge. Figure 1b shows the corresponding roughness layer of the terrain, which is mostly due to forests.



(a) (b)

Figure 1. Maps of the Hell's Canyon terrain elevation (a) and 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. Due the large domain size, the region is split into two areas for the north and south ends of the canyon. The separated regions are 33 km in the north-south region, with about 6 km of overlap in a region containing two weather stations. The WindSim CFD simulations are first run separately for each of these areas. The total number of cells for the each of the simulations is about 48 million. The x-y mesh of the entire terrain is shown in Figure 2, along with the vertical spacing. The vertical grid spacing varies greatly between the high elevation mountain regions and lower river portions of the terrain.

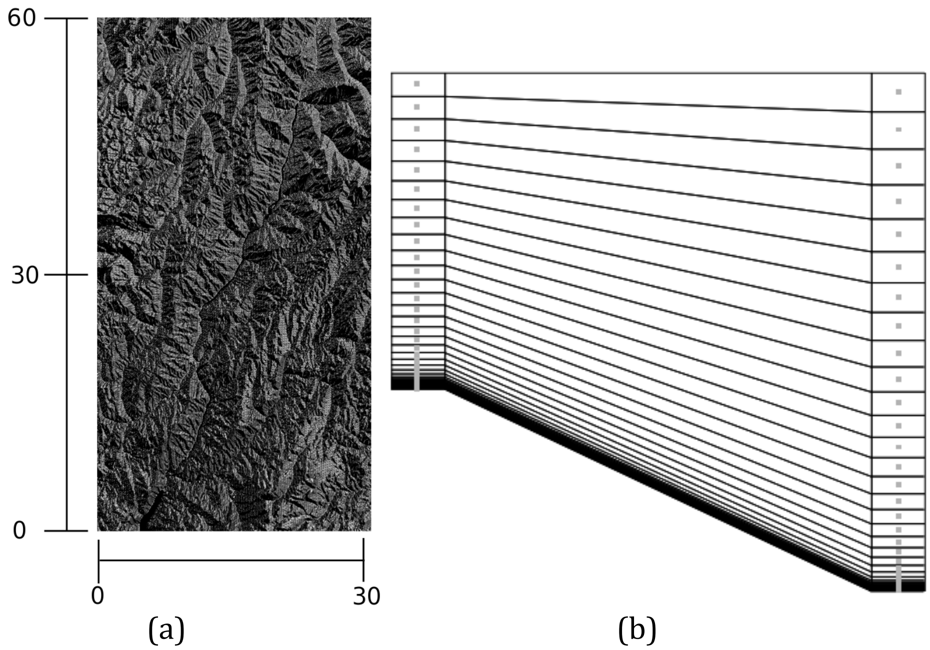


Figure 2. The x-y (a) mesh of the total region, and the vertical spacing of the mesh (b)

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 set to be 10 m/s for the CFD results, but this is scaled based on the specific climatology data taken from the previously collected weather station data in post-processing steps.

The CFD simulation is run in parallel for each of the two regions on 12 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 for both the north and the south sections are shown in Figure 3a and 3b for the north incoming wind (one of the prevailing directions) at 10, 50 and 100 meters above ground level. The drastic changes in elevation in the region create stagnation zones near the ground layer, and many areas near steep terrain show nearly no wind from the incoming north direction for the 10-meter height. As the height above ground in increased, stagnation zones are less likely and the wind speed shows higher values.

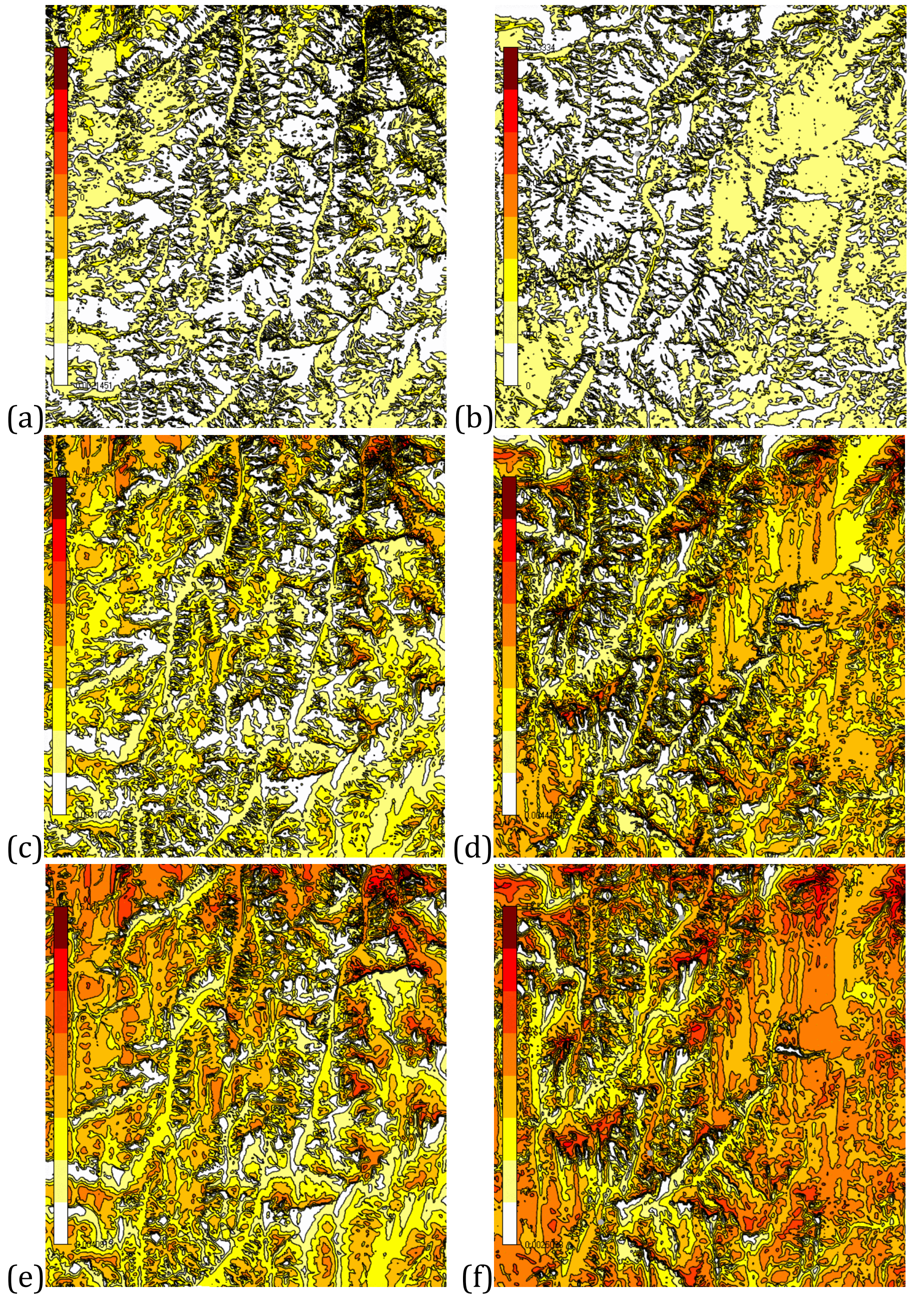


Figure 3. North (a,c,e) and South (b,d,f) sections showing wind speeds for one wind sector at 10, 50 and 100 meters above ground level – unscaled results.

The simulations are run with a base wind speed of 10 m/s, using this data wind speedup and directional changes are calculated, and then appropriately scaled according to historical data from weather stations. 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. For the center region where the two domains overlap there are two weather stations, the wind roses for these based on the data gathered are shown in Figure 4. The wind is predominately from the north with some southerly winds based around the second station.

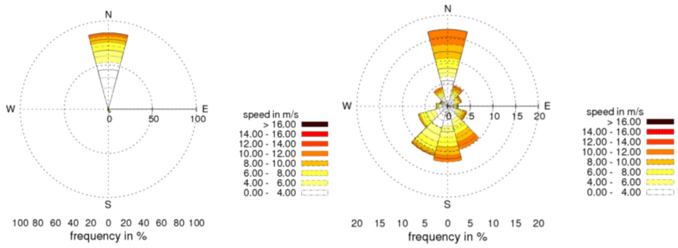


Figure 4. Windroses of the two weather stations in overlap region, showing most prevailing winds from the north in this area of interest.

Figure 5 shows the midpoint and weather station locations, as well as highlighting the overlapping region of the two CFD simulations. This section contains one of the greatest elevation changes along the power line of interest, as the power lines traverse out of the main canyon, the elevation changes from about 500 to 1600 meters This region contains two weather stations and 27 midpoints. It is expected that the region along the boundary of the domains would stand to gain the most information from utilizing the Wind Atlas methodology.

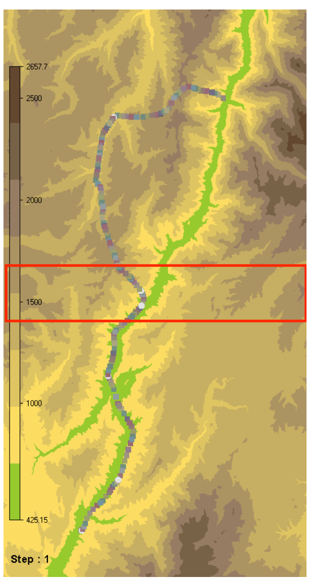


Figure 5. Full terrain showing midpoint locations as squares forming the meandering path of the transmission line and weather stations as circles. The overlapping region is highlighted in red.

For the calculations of the dynamic line ratings, several additional factors are taken into account; the mechanical properties of the line (industry standard specifications for a given type of conductor) determine its heat transfer parameters. Parameters such as emissivity, thermal conductivity, and the surface area of the conductor are considered in these ampacity calculations. The current capacity (ampacity) can be calculated from the combination of the convective heat loss (from the CFD), the irradiative 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]. In the future, the difference in GLASS calculations using small sections versus using the wind atlas method will be analyzed to determine the conservative nature of the estimates.

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 scaled predictions over a large region of interest. This has been done on a large region containing complex terrain that required splitting of the region into multiple CFD domains. In the future, an in-depth validation will be used to provide confidence in the results of the CFD model.

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 increase the line ratings as needed based on local weather conditions, or adapt to power demand. We are seeking to analyze the benefits of the Wind Atlas method for this type of system.

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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, 1993.