



Dynamic rating of overhead transmission lines over complex terrain using a large-eddy simulation paradigm



Tyler Phillips^a, Rey DeLeon^{a, b}, Inanc Senocak^{a, *}

^a Department of Mechanical & Biomedical Engineering, Boise State University, Boise, ID, 83725, United States

^b Department of Mechanical Engineering, University of Idaho, Moscow, ID, 83844, United States

ARTICLE INFO

Article history:

Received 1 October 2016

Received in revised form

21 February 2017

Accepted 24 February 2017

Available online 27 February 2017

Keywords:

Computational fluid dynamics

Dynamic line rating

Wind power

ABSTRACT

Dynamic Line Rating (DLR) enables rating of power line conductors using real-time weather conditions. Conductors are typically operated based on a conservative static rating that assumes worst case weather conditions to avoid line sagging to unsafe levels. Static ratings can cause unnecessary congestion on transmission lines. To address this potential issue, a simulation-based dynamic line rating approach is applied to an area with moderately complex terrain. A micro-scale wind solver — accelerated on multiple graphics processing units (GPUs) — is deployed to compute wind speed and direction in the vicinity of powerlines. The wind solver adopts the large-eddy simulation technique and the immersed boundary method with fine spatial resolutions to improve the accuracy of wind field predictions. Statistical analysis of simulated winds compare favorably against wind data collected at multiple weather stations across the testbed area. The simulation data is then used to compute excess transmission capacity that may not be utilized because of a static rating practice. Our results show that the present multi-GPU accelerated simulation-based approach — supported with transient calculation of conductor temperature with high-order schemes — could be used as a non-intrusive smart-grid technology to increase transmission capacity on existing lines.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Investments in renewable energy has been driven by several factors, including energy security and stability, climate change, and economics. Since 2000, wind energy has been the largest source of new renewable generation installed in the United States [1]. However, wind power generation is much more complex than installing wind turbines in windy areas. Grid integration is a major challenge, many of the best locations for wind farms do not have access to the needed transmission capacity [2]. Congestion in existing transmission lines is a growing concern, resulting in inefficiencies for both renewable energy producers, utilities and balancing authorities [3]. At times, transmission service providers (TSPs) may not be able to absorb the power generated, therefore, power production can be curtailed.

Potential sites for wind power generation are usually found in remote open areas that are away from populated cities, where electricity is needed most. Historically, transmission systems have

been built together with power production installations in order to meet the electricity demand. For economic reasons they are usually not over-sized, therefore, current transmission networks in many of these sites may not support additional generation. Many wind projects have been able to patch into the existing transmission network, however, these opportunities are shrinking. Further expansion of wind energy may require large investments in transmission networks, creating an obstacle for cost-effective wind deployment [1,4].

Transmission capacity can be increased in several ways. The obvious way is to reinforce the transmission network with new powerlines. However, this is constrained by the high costs and legal challenges of building new powerlines [5]. Therefore, TSPs have focused on innovative solutions that modifies existing network to increase transmission capacity. Different techniques include prediction of meteorological conditions by means of deterministic [6] or probabilistic [7] forecasting methods, and adopting the newest innovations in smart-grid real-time monitoring of temperature, sag, tilt, power, current and weather conditions [8–10]. In the case of wind energy integration, monitoring meteorological conditions in real-time can be very beneficial for both power generation and

* Corresponding author.

E-mail address: senocak@boisestate.edu (I. Senocak).

transmission purposes. Strong winds needed for wind generation, will also cool down the conductor of local transmission lines, creating additional capacity, which would enable TSPs to “overload” the line when it is needed most [11,12].

Transmission conductor capacity is limited by its maximum allowable temperature. The maximum amount of electric current a conductor can transmit before structural damage is known as *ampacity*. Currently, ampacity is generally determined using a static line rating (SLR) methodology. SLR is based on conservative assumptions regarding environmental conditions, such as high ambient temperature and low wind conditions. These assumptions were made to avoid lines sagging to unsafe levels. However, they are overly conservative for areas where wind generation is abundant. Therefore, TSPs are investigating dynamic line rating (DLR) methods to increase ampacity on existing lines. DLR utilizes real-time environmental conditions to better predict the temperature of the conductor. Deployment of DLR has the potential to reduce the estimated \$60 billion needed in transmission infrastructure to meet the 20% wind energy by 2030 [2].

Fernandez et al. [13] provide a comprehensive review of real-time DLR technologies that have been developed over the last 30 years, endorsing the potential of DLR for wind power integration. Commercially available DLR technologies include direct line sag, line tension, and conductor temperature measurements [14]. Wind turbines are increasingly being built in areas of complex terrain, as available sites on flat terrain is diminishing. In complex terrain elevated positions like hill tops are favorable sites due to the increased wind speed. However, complex terrain proves to be challenging for the aforementioned DLR systems. Sag and tension monitoring systems can only inform TSPs of the average sag or tension measurement over large sectionalized transmission spans, therefore, only the average temperature of the conductor over large sections can be known. Direct temperature measurements at a single location may not necessarily represent the critical span, or the hottest section along a conductor. Studies have shown that conductor temperature can vary spatially by 10–20 °C due to variations in wind speed and direction [15–17]. Therefore, currently adopted DLR systems may not be a good solution for determining the real-time transmission capacity in regions of complex terrain. If implemented, they may potentially lead to severe overestimation of the actual ratings, allowing the conductor to be overloaded and causing degradation of the line. Adding more monitoring devices could be a solution, however these systems are typically expensive for wide deployment that is needed to reduce risks to an acceptable level [18]. Additionally, implementation of direct DLR systems can prove to be challenging, as transmission lines need to be de-energized during installation and regular maintenance. Therefore, a non-intrusive DLR solution is highly desirable, which also motivates the present study.

In Greenwood et al. [19] two non-intrusive approaches were compared. One approach adopted a CFD-based library approach to extract wind speeds and direction along the path of transmission lines and the other approach used an uncertainty model based on a small number of weather stations. Greenwood et al. suggested that a more sophisticated wind model that can accurately capture the time-dependent nature of winds over complex terrain coupled with uncertainty quantification would be invaluable to expand the DLR concept. Michiorri et al. [20] used actual environmental conditions from a limited number of meteorological stations as input to the steady-state thermal models. An inverse distance interpolation technique and a power law for wind profile were used to estimate the environmental conditions at transmission line. A state-estimation algorithm based on the Monte-Carlo approach was then used to take into account the uncertainty in data. Michiorri et al. identified the source of errors as the physical models used in

their approach, and suggested the use of wind flow models based on the computational fluid dynamics (CFD) approach.

With today's improved wind and weather modeling and high performance computing capabilities, the use of computer simulations to forecast wind and determine transmission capacity has emerged as an alternative to intrusive hardware solutions. Short-term wind forecasting can potentially be a valuable tool for TSPs, enabling conductor temperature calculations at dense intervals along transmission lines in complex terrain. Michiorri et al. [21] reviewed current meteorological forecasting technologies for broadening the adoption of DLR and particularly drew attention to the current need to improve low wind speed modeling and turbulence. Michiorri et al. promote the viewpoint of moving from monitoring technologies to an active management technology where wind forecasting for different time horizons becomes critical. To this end, our large-eddy simulation approach directly addresses the need to improve low wind speed modeling in the vicinity of transmission lines.

Meso-scale numerical weather prediction models have long been used to forecast winds and other meteorological variables, however their application to micro-scale atmospheric boundary layer flows over complex terrain with a horizontal spatial resolution ranging from 10 to 100 m is still an on-going research and far from realizing the forecasting mode. Mesoscale weather forecasting models typically adopt spatial resolutions on the order of a few kilometers. Results from existing forecasting models vary greatly depending on the locations and time period investigated [22–26]. On relatively flat terrain use of mesoscale models may prove effective, but fine-scale forecasting solutions that can resolve complex terrain features with horizontal resolution on the order of 10 m are needed. For instance micro-scale complex terrain forecasting models could be used to quantify the stochastic variations in line ratings, which could then be converted to dynamic constraints as described by Banerjee et al. [27].

In what follows, we present the equations for dynamic line rating, followed by our massively-parallel, micro-scale wind solver to predict wind speed and direction as a function of time. An actual test area with moderately complex terrain is simulated, and predictions are compared against available weather station data at multiple locations. Field and simulation data are then used to compute available ampacity for a dynamic line rating scenario, demonstrating the potential of the current non-intrusive approach to increase transmission capacity.

2. IEEE standard 738-2012 transmission capacity calculation

Transmission line capacity is commonly calculated using procedures described either in the Institute of Electrical and Electronics Engineers (IEEE) 738 Standard [28] or the CIGRE Standard [29]. In this study, we follow the IEEE standard and describe the salient features of the calculation procedure for clarity.

Temperature of an overhead electrical conductor is a function of its material properties, weather conditions, and electrical current. The steady-state heat balance is given as

$$q_c + q_r = q_s + q_j, \quad (1)$$

where q_c , q_r , q_s , and q_j are the conductor convective heat loss, radiated heat loss, solar heat gain, and Joule heating, respectively.

Joule heating is calculated using the electric current, I , and conductor resistance, $R(T_{ave})$, which is a function of its average temperature, T_{ave} . Joule heating is given as

$$q_j = I^2 \cdot R(T_{ave}). \quad (2)$$

Download English Version:

<https://daneshyari.com/en/article/4926520>

Download Persian Version:

<https://daneshyari.com/article/4926520>

[Daneshyari.com](https://daneshyari.com)