

Dynamic Thermal Rating of Power Transmission Lines Related to Wind Energy Integration

Jana Heckenbergerová^{1,3}

¹Dept. of Mathematics and Physics,
Faculty of El. Eng. and Inf., University of Pardubice
Pardubice, Czech Republic
Jana.Heckenbergerova@upce.cz

Jiří Hošek^{2,3}

²Inst. of Atmospheric Sciences & ³Inst. of Computer Science
Academy of Sciences
Prague, Czech Republic
hosek@ufa.cas.cz

Abstract—The installations of weather-dependent renewable energy sources, such as wind turbines and solar plants, increased significantly in the last two decades. They are often built in remote areas without appropriate power grid connections. The construction of a new power transmission line or improving the old one requires significant financial and time costs. The grid operators prefer to limit the power production in order to keep the load of the power line under its rating. Instead of broadly-used static rating, the existing lines can be rated in real time using a dynamic thermal rating (DTR) system. DTR of power transmission lines can usually provide a significant increase of transmission capacity compared to the static rating. The main inputs to DTR systems are measured or forecast meteorological data.

The relation of DTR to the renewable resources is obvious when we consider input parameters to the calculation scheme – wind speed, ambient temperature and shortwave radiation. Exactly same variables are determining production of wind and solar energy. A case study of virtual wind farm and corresponding power transmission line shows limits of renewable energy production at given site. The results demonstrate that the optimal size of wind farm is approximately triple when using DTR comparing to the static rating.

Keywords-dynamic thermal rating; wind energy; power transmission

I. INTRODUCTION

Nowadays, power transmission lines are often operated close to their thermal limits because of constantly growing electricity demand and generation [1]. Furthermore for last two decades, significant decentralization of electricity production have been caused by booming of modern renewable energy sources, such as solar plants and wind turbines. In particular, new wind farms have been built in remote areas that often lack suitable power grid connections, and can lead to system congestion. Constructing a new power transmission line, or reconductoring an old line are some of the possible solutions; however, such upgrades require a significant investment, and take a long time to deploy. Utilization of more accurate assessment of the climatic conditions along the transmission corridor is a cheaper alternative for uprating the current-carrying capacity of the power lines.

The static thermal rating of a transmission line is usually based on the type of conductor and conservative estimates of the climatology of the site. The dynamic thermal rating (DTR) system, using the actual operating conditions, represents a potential, significant improvement over the more traditional rating methods [2]. The online monitored data, such as conductor temperature, sag, or weather conditions, are processed to calculate the additional line capacity available for power transmission. In order to implement a weather-based DTR system, a conductor thermal model with observed or forecast meteorological data is required.

Advantages of using DTR system related to effective wind power integration to the distribution system are introduced in this paper. As the onshore wind power is often produced at sites with limited power grid availability, the distribution authority often cap the production with certain threshold making the rest wasted on the windy days. It is shown that utilization of DTR of power transmission line conductors can significantly decrease the wasted production of the wind farm. The main reason for such result is high correlation between line current-capacity and wind power generation.

This paper consists 5 sections. Section II. describes background of conductor thermal rating. Methodology and source data are summarized in section III. Results of a case study are presented and analyzed in section IV. The last section provides major conclusions and indicates directions of our future work.

II. THERMAL RATING BACKGROUND

The thermal limit of the conductor is the most significant restriction on electric power transmission through overhead lines. Conductor overheating can cause its irreversible elongation due to the loss of tensile strength; this effect is known as annealing [3], [4]. Another negative consequence caused by high conductor temperatures is increasing of conductor sag that subsequently may result in clearance violations. To avoid these problems, current-carrying conductors are rated in terms of the maximum current, known as ampacity, they can safely transport, without a substantial risk of thermal overload, e.g. conductor temperature $T_c = 95^\circ\text{C}$.

For evaluation of power transmission conductor thermal rating, there are two main approaches generally used. The first is the static rating that assumes a conservative scenario for calculating the steady-state ampacity: high ambient temperature, low wind speed and high solar radiation. However under the true worst-case conditions (e.g. extreme ambient temperatures combined with full solar radiation and no wind), even such a conservative rating may not be sufficient. Under these critical conditions, which can happen with a probability of a few percent depending on the rating assumptions and climate of the site, the actual ampacity may be lower than the static rating and it is leading to an inadvertent thermal overload of the conductor. The static rating method can be improved by using climatological data for the site, accepting the risk of line thermal overload (risk tolerance is usually set to 0-5%) and calculating the ampacity for individual seasons, or months of the year [5].

Dynamic rating methods provide ampacity either directly, based on actual measurements of conductor conditions (e.g. temperature or sag), or indirectly, using ambient weather conditions. In general, DTR systems yield values of ampacity higher than the static methods; under typical mid-latitude climatic conditions, DTR is twice as big as the static ampacity on average [6]. This occurs because actual meteorological conditions are often more favorable than the conservative assumptions used for the static rating.

Evaluation of the heat balance equation (HB) of the conductor (1) is the basic principle of weather-based DTR calculations:

$$q_c + q_r + mC_p \frac{dT_c}{dt} = q_s + I^2 R(T_c) \quad (1)$$

where q_c and q_r are the heat losses due to convection and long wave radiation, q_s and $I^2 R(T_c)$ are the heat gains due to solar radiation and Joule heating and the term mC_p is the heat capacity of the conductor. Under the assumption that the conductor temperature has already reached equilibrium and the derivative dT_c/dt is equal to zero, the conductor ampacity is calculated for steady state conditions. Adapted equation is then solved for current I , corresponding to ampacity, with T_c set to the maximum safe conductor temperature. The transient thermal rating is calculated, when current and/or ambient conditions are varying. The heat balance equation then needs to be solved numerically at each time step with respect to a specific time period and with keeping the derivative dT_c/dt at its actual value. A number of variables has to be considered to evaluate all terms in the HB equation (1). They define conductor electrical and physical parameters along with environment and ambient weather conditions [7]. The weather parameters that are usually measured for DTR purposes include ambient air temperature, wind speed and direction, and solar radiation; the latter can also be easily calculated for clear-sky days. Non-constant conductor parameters such as sag or surface temperature has to be measured as well.

Several industrial standards have been developed for assessing the temperature and ampacity of overhead conductors and for operational DTR implementation. Nevertheless, only two of them are commonly used: the IEEE Standard 738 [8], and the CIGRE method [9]. These two approaches were

compared in a study by Schmidt [10] that found no significant differences in their results. For the purposes of this study, a procedure based on the IEEE method is used to calculate the dynamic thermal ratings.

III. SETUP OF THE CASE STUDY AND SOURCE DATA

The following case study demonstrates the possible advantage of DTR utilization for power lines connecting the wind energy sources. For that purpose, we had to consider a wind farm production and a transmission line connecting it to the main grid. A professional wind speed measurement was available at appropriate site and we preferred to simulate the wind energy production with a typical power curve rather than use real data, which might have been affected by maintenance and other irregularities. The site is located in Ore Mountains extending from southwest to northeast along the border with Germany. The region is the most important source of wind energy production in the Czech Republic.. The transmission line is considered connecting the wind farm and the urbanized areas and with parameters typical for the region.

The production of wind farms is based on the wind speed measurements at an elevated site of Dlouha Louka in Ore Mountains (altitude: 890 m a.s.l.). This site is one of the windiest in the country, and the measurements were originally taken for wind energy assessment purposes. The most frequent and strongest winds come from the west and northwest, while the terrain opens to the south with an aspect of approximately 190°. The ultrasonic anemometer is placed on top of a meteorological mast with height of 50 m a.g.l. The long-time average wind speed, in the period 1994 to 2004, at 50 m was 7.04 m/s.

The meteorological data for DTR calculations are based on supposed least windy end of the line in the valley. The standard synoptic meteorological station in Teplice fulfills the required position. The site has elevation 230 m a.s.l. and measurements are taken with standard cup anemometer at 10 m a.g.l.

The period of parallel availability of data covers the period from April 2003 to April 2005, which also defines the analyzed time interval. As the measurements were closer to the surface than required height, the wind speed measurements had to be transformed to the height above ground corresponding to the height of transmission lines and wind turbines (WTs). It was 30 m a.g.l. for DTR calculations and 98 m a.g.l for WT production calculations. The logarithmic profile was used for height adjustment based on the local surface roughness.

Most of the local power lines connecting WTs are underground, so the DTR calculations have no sense in that case. Therefore, the line parameters were chosen to reflect common midsize transmission system line - with voltage of 110kV - delivering the power from the elevated region with wind energy production to the neighboring industrialized valley. The conductor considered was AlFe6 120mm² with outer diameter 31.3 mm. The resistance at 75°C is 0.234 ohm/km according to the specifications. The static ampacity declared is 420A calculated for 0.6 m/s wind speed, wind direction parallel to the line, 30°C ambient temperature and 300 W/m² solar radiation.

In the studied region, many types of WTs appear - predominantly of 80-90 m diameter and 90-105 m hub height. However, the power curve of the chosen type E82 does not differ much from WTs of other brands in this category. The wind turbine has a rotor with diameter 82 m and generator with nominal power 2300 kW.

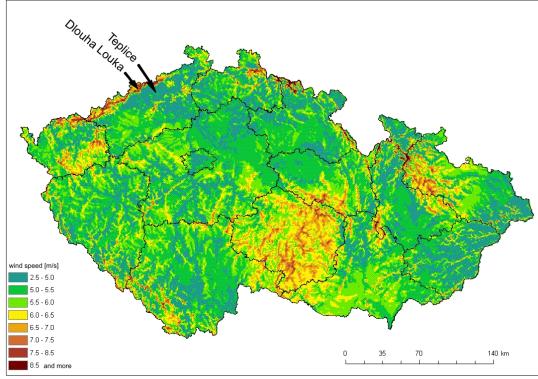


Figure 1. Location of meteorological measurements and map of the mean wind speed [m/s] in the Czech Republic.

IV. RESULTS OF THE CASE STUDY

With the above-mentioned setup, the wind energy production and the line capacity was calculated. In the studied region the transmission takes typically half of the line capacity defined with static rating. Therefore, 240A of the total capacity was considered blocked with other traffic, leaving 180A available for transport of energy produced by WTs in case of static rating. Variable size of the wind farm was tested, starting at 10 WTs. Three scenarios are highlighted that define various levels of excess production:

- 1) 13 WTs, max. current delivered 272 A, i.e. cca 150% of free capacity;
- 2) 17 WTs, max. current delivered 356 A, i.e. cca 200% of free capacity;
- 3) 26 WTs, max. current delivered 544 A, i.e. cca 300% of free capacity;

The results of those three setups are shown in Fig. 2, 3 and 4. These figures display the frequency histograms of the difference between line ampacity required to transmit the wind farm production and available ampacity for static resp. dynamic thermal rating utilization. The positive numbers define the wasted production that cannot be transported. Due to the properties of wind power production, the total portion of cases exceeding the static rating was not significantly different for smallest (Fig. 2), medium (Fig. 3) and largest (Fig. 4) wind farm. On the other hand, the differences between the required and available ampacity (i.e. wasted production) depended significantly on the scenario. The probability that the production exceeds DTR is very small for the largest wind farm and negligible for the other two scenarios. The main reason for such result is high correlation between line ampacity and wind power generation caused by dependance of both on actual wind speed.

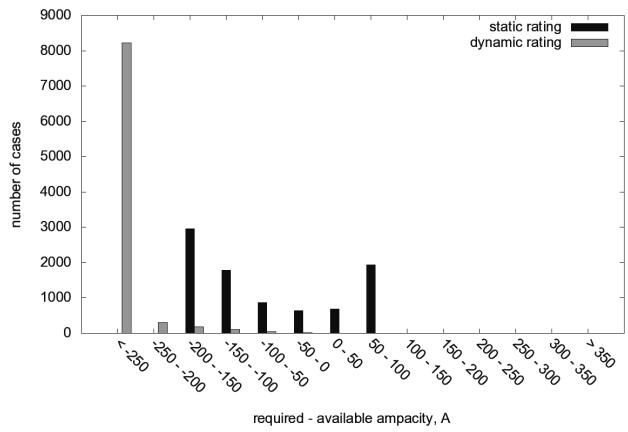


Figure 2. Difference of required and available ampacity for a wind farm with 13 WTs.

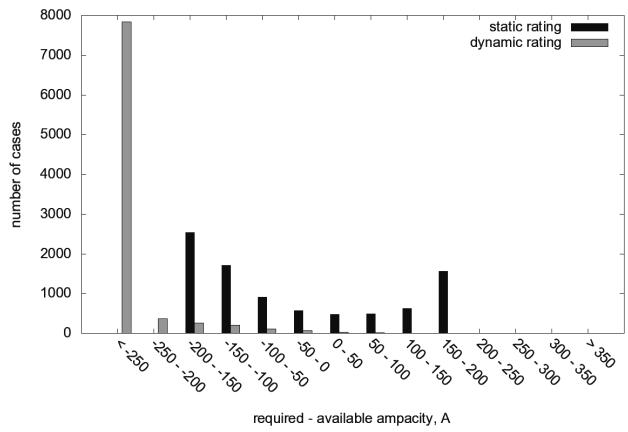


Figure 3. Difference of required and available ampacity for a wind farm with 17 WTs.

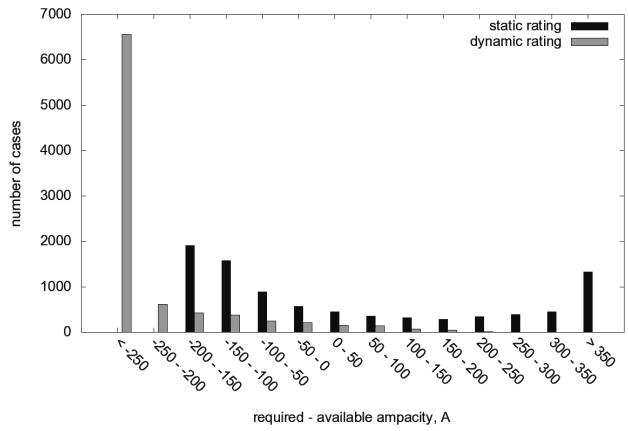


Figure 4. Difference of required and available ampacity for a wind farm with 26 WTs.

The wasted production in the given period can also be expressed as a function of number of WTs in the wind farm (Fig. 5). While for static rating it increases approximately linearly, the function is much smaller and exponential in case of DTR that allows better finding an optimal size of wind farm. Supposing only minimal wasted production, the wind farm would only contain 9 WTs when using static rating comparing to 27 WTs with DTR involved.

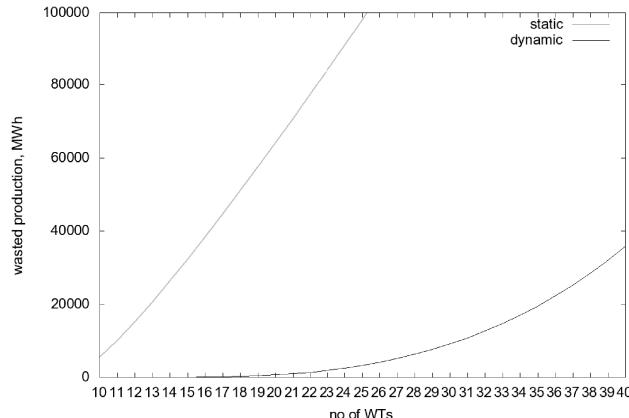


Figure 5. Wasted production of considered wind farm with 10 to 40 WTs.

V. CONCLUSION

In this contribution, advantages of using DTR system related to effective wind power integration to the distribution system are introduced. Theoretical background of the line thermal rating is augmented with the case study. The test site of this study is one of the windiest in the country, and used measurements were originally taken for wind energy assessment purposes.

In principle, our results show that the dynamic thermal rating allows more line capacity than static rating. As the line ampacity strongly increases with the incoming wind speed, the local power line connected to the wind turbine is supposed to be able to transport more of the energy comparing to the static rating. If the nominal power of connected WTs is close to the line capacity according to the static rating, DTR helps to transport the energy otherwise wasted. In the presented case study, the optimal size of wind farm is approximately triple when using DTR comparing to the static rating.

Utilization of dynamic thermal rating methods for the local distribution lines connecting the wind farms to the transmission network can significantly increase transmitted power and decrease the wasted production of the farm. Moreover, DTR can help with economical optimization of the whole system and size of the farm can be increased without violation of thermal limit restrictions.

ACKNOWLEDGMENT

This work has been supported by the Grant Agency of the Academy of Sciences of the Czech Republic No. M100300904 and partly supported by the MSMT Institutional funds at the University of Pardubice.

REFERENCES

- [1] Carreras B. A., Newman D. E., Dobson I., and Poole A. B., "Evidence for self-organized criticality in a time series of electric power system blackouts," *IEEE Transactions On Circuits And Systems*, vol. 51, no. 9, pp. 1733–1740, September 2004.
- [2] Douglass D.A., "Weather-dependent versus static thermal line ratings (power overhead lines)," *IEEE Transactions on Power Delivery*, vol.3, no. 2, pp. 742–753, Apr. 1988.
- [3] Bhuiyan M.M.I., Musilek P., Heckenbergerova J., and Koval D., "Evaluating thermal aging characteristics of electric power transmission lines," in *IEEE 23rd Canadian Conference on Electrical and Computer Engineering (CCECE 2010)*, Calgary, AB, Canada, May 2-5, 2010, print ISBN: 978-1-4244-5376-4, ISSN: 0840-7789 (4 pages)
- [4] Heckenbergerova J., Musilek P., Bhuiyan M.M.I., Koval D., and Pelikan E., "Identification of critical aging segments and hotspots of power transmission line," in *9th International Conference of Environment and Electrical Engineering (EEEIC 2010)*, Prague, Czech Republic, May 16-19, 2010, pp. 175-178, ISBN: 978-1-4244-5370-2.
- [5] Heckenbergerova, J., Musilek, P., Filimonenkov, K., "Assessment of Seasonal Static Thermal Ratings of Overhead Transmission Conductors," in *2011 IEEE Power & Energy Society (PES) General Meeting*, Detroit, USA, July 24-29, 2011, ISBN: 978-1-4577-1001-8.
- [6] Hall, J.F., and Deb, A.K., "Prediction of overhead transmission line ampacity by stochastic and deterministic models," *IEEE Trans. on Power Delivery*, vol.3, no. 2, pp. 789–800, Apr. 1988.
- [7] Hosek J., Musilek P., Lozowski E., Pytlak P.: "Effect of time resolution of meteorological inputs on dynamic thermal rating calculations," accepted to *IET Generation, Transmission & Distribution*
- [8] IEEE, "Standard for calculating the current-temperature of bare overhead conductors, Std 738," 2006.
- [9] CIGRE Working Group 22.12, "Thermal behaviour of overhead conductors," 2002.
- [10] Schmidt N.P., "Comparison between IEEE and CIGRE ampacity standards," *IEEE Transactions on Power Delivery*, vol. 14, no. 4, pp.1555 –1559, Oct 1999.