Network Planning Case Study Utilising Real-Time Thermal Ratings and Computational Fluid Dynamics

David GREENWOOD
Durham University – UK
d.m.greenwood@dur.ac.uk

Grant INGRAM
Durham University – UK
g.l.ingram@dur.ac.uk

Phil TAYLOR
Durham University – UK
p.c.taylor@dur.ac.uk

Alan COLLINSON
SP Energy Networks – UK
alan.collinson@sppowersystems.com

Sarah BROWN
Astrium GEO- Information Services – UK
sarah.brown@infoterra-global.com

ABSTRACT

Real-Time Thermal Ratings (RTTR) has a natural synergy with wind generation, since during periods of high local wind speed increased wind farm output coincides with uplifted line ratings.

This paper describes a network planning study on a real section of UK distribution network. The study considers a branch of 132kV network connecting several wind farms to the grid. By assessing the local wind conditions in the area surrounding the wind farm and proposed overhead line, the study predicts the increase in energy throughput, and hence accommodated generation, for different routes considered for the overhead line. The locations of thermal bottlenecks in the proposed routes are identified. The study shows that a wind farm of 140MW can be connected to a conductor which could only support 90MW based on its static rating, and if the route is chosen correctly only 1% of the energy yield will be constrained.

INTRODUCTION

Real-time rating comes from the observation that the first limit of a current carrying conductor is its temperature. The conductor is heated by the joule effect and incident solar radiation, while being cooled by the local wind, the lower ambient temperature of the surrounding air and radiation. This gives an energy balance, as shown in figure 1.

$$I^2R + Q_s = Q_c + Q_r \qquad (1)$$

Equation 1 shows this energy balance mathematically, with I^2R being the heating from the joule effect, Q_s the heating from incident solar radiation, Q_c is the cooling by convection and Q_r is heat loss through radiation. These are used to calculate the conductor's rating based on a maximum acceptable temperature. This temperature is set such that it will not reduce component lifetime and that the associated thermal expansions will not cause the line to sag dangerously low.

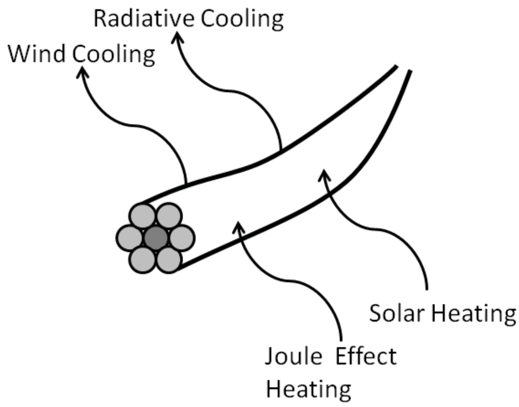

Figure 1: The energy balance in an electrical conductor

This low risk scenario is represented by a conservative set of weather conditions; 0.5m/s wind speed parallel to the line and no incident solar radiation. The ambient temperature is varied based on season to give winter, summer and spring/autumn ratings [1, 2]. RTTR replaces these conservative ratings with real-time weather observations to increase conductor ratings and therefore energy throughput. An example of the additional capacity available is shown in figure 2. This was calculated using real weather observations and the CIGRE model for a lynx conductor [3].

Wind speed is the single parameter which has the greatest effect on overhead conductor rating [4]. As such, there is a natural synergy between enhanced ratings due to high wind speed, and power output from local wind generation. This provides part of the motivation for this case study. The other motivation is that the expansion of wind generation can often appear unfeasible given the electrical network it must connect to. By employing RTTR at the planning stage, operators can be aware of the additional capacity that the wind generators will be able to exploit during operation. Though this capacity will not be available continuously, used in conjunction with distributed generator control it can significantly increase the energy output of a wind farm [5].

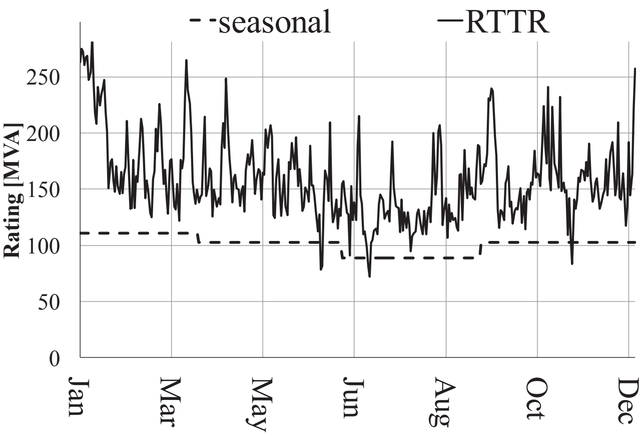

Figure 2: Comparison of static rating and real time thermal rating.

METHODOLOGY

Description of Case Study

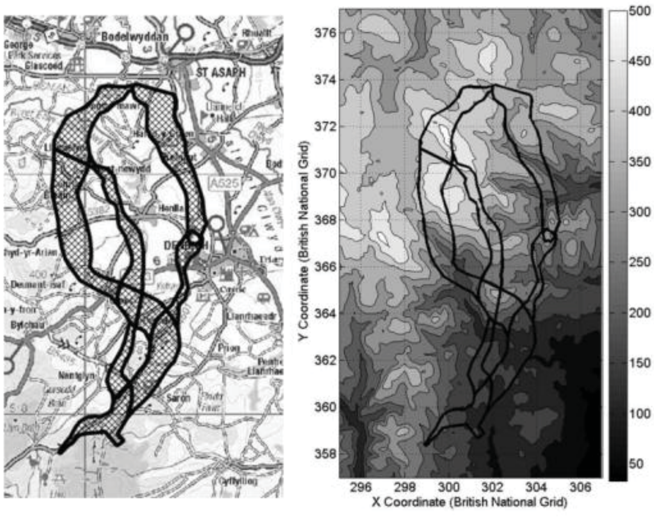

Figure 3: A map of the case study area showing the route corridors for potential overhead lines (left), and the elevations of the local terrain (m) (right)

The case study for this paper is an area of north Wales, just south of the town of St Asaph. Several wind farms are attempting to connect to the 132kV network, which requires the construction of a new overhead line. The potential routes for this conductor are shown in figure 3.

CFD Methodology

CFD has been increasingly used for planning in the wind energy industry, assisting in turbine siting and energy yield prediction. These methods have been applied here to aid selection of overhead line routes and identify thermal bottlenecks in the network. Calculations were run using FLUENT 12.1. The incoming flow direction was altered in 10° steps to represent a variety of prevailing wind conditions. A model was constructed using local terrain data, meteorological data and network data. The terrain data comprises two parts; local elevation data[1] and land coverage data[2]. The elevation data are used to create a surface around which a mesh is constructed. The land coverage data are then super imposed over the terrain as a grid of surface roughness. The mesh comprised approximately 3.5million cells, and the approximate run time for each calculation was 1 hour.

The simulations used an RNG k-ε turbulence model. The working fluid was modelled as air and the solids as aluminium. The inlets were velocity inlets, and the outlets pressure outlets. The air temperature was set at 300k and a logarithmic boundary profile used, as suggested in [6]. This methodology had previously been validated by the authors using the Bolund Hill Experiment [7]

The CFD results are used to generate a grid of normalised wind speeds across the area of interest. This is done by taking a surface of points 10m above the terrain and applying equation 1.

$$S_i = \frac{v_i}{\bar{v}} \qquad (1)$$

Where S_i is the normalised wind speed or speedup factor at a point i, v_i is the velocity at point i and $\bar{v}$ is the mean wind speed of all the points considered.

These speedup values were used in conjunction with observed weather data to estimate the wind speed at each point in the 10m surface for each observation at a meteorological station. For each observation, speedup values for the wind direction data set closest to the observed wind speeds are multiplied by the observed wind speed. Hourly data is used for the analysis, since the planning study is concerned with long term, aggregated effects rather than short term high variance events.

Ratings Calculation Methodology

Once the wind speeds were established, the rating of an overhead conductor at each point in the 10m layer was calculated at each time point in the weather data set. These data were calculated using the CIGRE line rating model [3], for a 20mm diameter lynx conductor. The temperature was assumed to be uniform across the domain. Since the conductor orientation was unknown the wind direction was assumed parallel to the conductor, which is the worst case scenario. Solar radiation was ignored.

---

1 © Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service
2 Data courtesy of Astrium Geo-Information Services

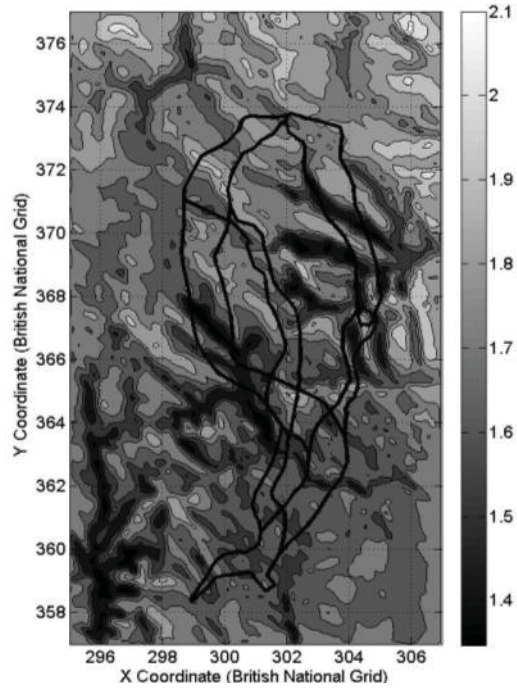

Figure 4: Map of annual average conductor rating as a proportion of seasonal ratings. The locations of the approved route corridors are shown on the plot.

This was used to calculate an annual average rating at each point in the domain, which is shown in figure 4. The ratings are shown in terms as a proportion of the seasonal ratings to give an indication of the additional capacity available. This would be useful for the identification of thermal hotspots, which could then be avoided when planning the overhead line route. These ratings suggest that the central route corridor would allow the largest wind farm to be connected. What this does not mean is that a line with an average rating of 60% above the seasonal could support a 60% larger wind farm. It is important to consider energy throughput rather than in terms of capacity.

The goal of this planning study is to maximise the energy output from a wind farm connected to the 132kV network by a new overhead line. Consequently it is more important to consider the energy output from the wind farm at the same time as the rating of the overhead lines.

ENERGY THROUGHPUT

To calculate the output of the wind farm, its location was assumed to be a single point at the end of the overhead line route. Wind data from this location was used with the simplified wind turbine power curve shown in figure 5 to calculate the power output for each hour. This was done for wind farms with an 80, 100, 120 and 140MW capacity.

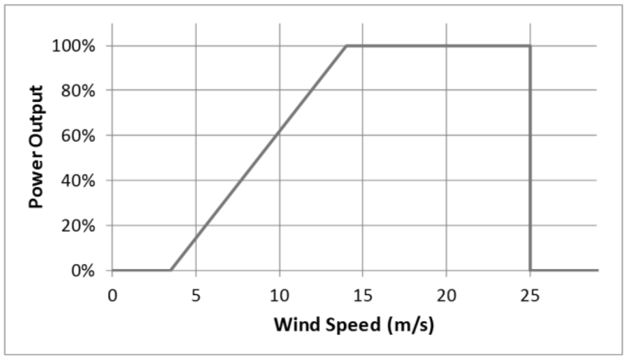

Figure 5: The wind turbine power curve used in this study

For each hour in the time series, the power output data for each wind farm was compared to the rating of a hypothetical overhead line at each point in the domain. If the rating was greater than the power output, then it was added into the energy throughput. If the rating was smaller than the power output, the rating of the line was added to the energy throughput, and the difference was added to the annual constrained energy.

The energy throughput data for a 120MW wind farm is shown in figure 6. There are low energy throughput areas similar to the low capacity regions in figure 4. However, the north western corridor now seems to be the best route, in spite of the comparatively low average rating.

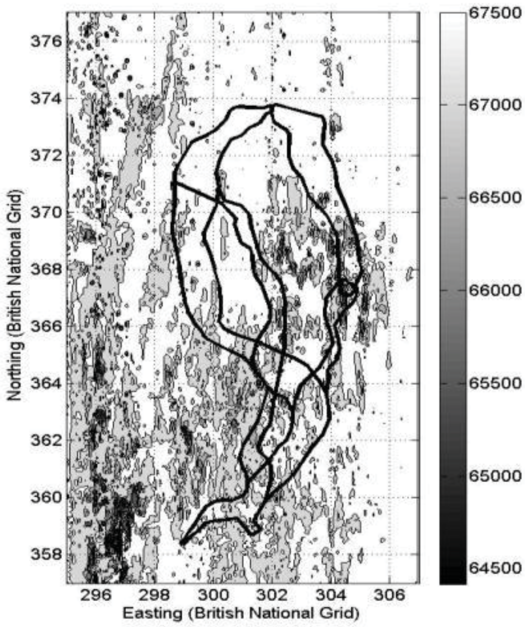

Figure 6: Energy throughput map for a 120MW Wind Generator (MWh)

A consequence of connecting a larger wind farm than the conductor is capable of supporting using its static rating is that the generator will sometimes have to be constrained. There have been a number of studies on constrained wind farm connections demonstrating that this is a realisable solution [8, 9]. Figure 8 shows the energy that would be constrained as a proportion of the total energy the wind farm would produce for a 140MW wind farm, the largest generator considered in this study. If the overhead line route is selected carefully the lost energy is small enough that the investment in a larger wind farm would be worthwhile.

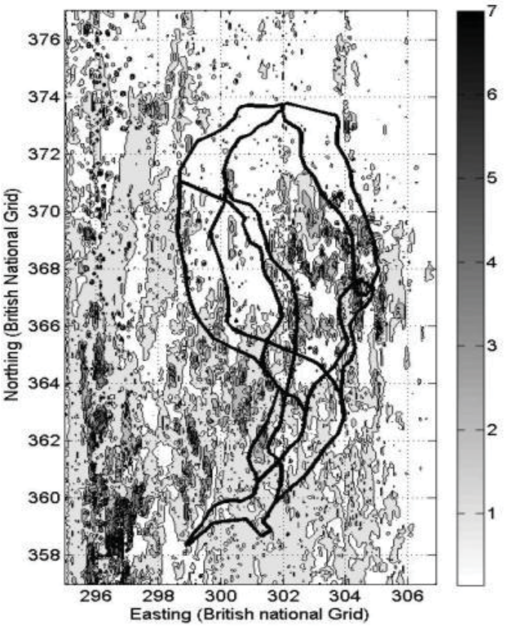

Figure 7: A map of constraints to wind generation as a proportion of the annual energy yield of a 140MW wind farm

These data suggest that from an energy yield perspective the best location for an overhead line connecting a wind farm in this area would be the northwest corridor, followed by the south east corridor. This suggests that 140MW of wind generation could be connected using an overhead line that would normally only support 90MW, with energy constraints of 1-2% of annual energy yield. However overhead line siting is a complex problem and many other factors must be considered.

CONCLUSION

This paper has discussed a planning methodology for using Real-Time Thermal Ratings to increase the size of a wind farm connected to a distribution network. Through CFD modelling it is possible to identify high and low wind areas which can be used to inform conductor route planning. Moreover, the energy that could be exported from different sizes of wind generator can be compared, leading to an understanding of the level of generation and constraint that could be attained.

A case study using a real wind farm connection in north Wales was considered, and the capability to connect a 140MW wind farm to a line that could only support 90MVA with a low level of constraint was demonstrated. If the overhead line was build through only high wind areas, the level of constraint could be as low as 1-2% of total energy yield. However, there are other factors governing the placement of overhead lines. Often conductors are sighted in areas such as valleys to minimise visual impact, when this will reduce the impact of wind cooling on the overhead line and consequently reduce the size of wind farm that can be connected.

REFERENCES

[1] C.F. Price and R.R. Gibbon, "Statistical approach to thermal rating of overhead lines for power transmission and distribution," *Generation, Transmission and Distribution, IEE Proceedings C,* vol. 130, pp. 245-256, 1983.

[2] Energy Networks Association, "Engineering Reccomendation P27: Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System," London: Energy Networks Association, 1986.

[3] Cigre Working Group 22.12, "The thermal behaviour of overhead line conductors," *Electra,* vol. 114(3), pp. 107-25, 1992.

[4] A. Michiorri, P.C. Taylor., S.C.E. Jupe, C.J. Berry, "Investigation into the influence of environmental conditions on power system ratings," *Proc. IMechE Vol. 223 Part A: J. Power and Energy,* pp. 743-757, 2009.

[5] P.C. Taylor and S.C.E. Jupe, "Distributed generation output control for network power flow management," *IET Renewable Power Generation,* vol. 3, pp. 371-386, 2009.

[6] P.J. Richards and S.E. Norris, "Appropriate boundary conditions for computational wind engineering models revisited," *Journal of Wind Engineering and Industrial Aerodynamics,* vol. 99, pp. 257-266, 2011.

[7] A. Bechmann, N. Sørensen, J. Berg, J. Mann, and P. E. Réthoré, "The Bolund Experiment, Part II: Blind Comparison of Microscale Flow Models," *Boundary-Layer Meteorology,* vol. 141, pp. 245-271, 2011.

[8] R.A.F. Currie, G.W. Ault, R.W. Fordyce, D.F. MacLeman, M. Smith, and J.R. McDonald, "Actively Managing Wind Farm Power Output," *Power Systems, IEEE Transactions on,* vol. 23, pp. 1523-1524, 2008.

[9] S.C.E. Jupe, P.C. Taylor, and A. Michiorri, "Coordinated output control of multiple distributed generation schemes," *Renewable Power Generation, IET,* vol. 4, pp. 283-297.