

Line Rating Optimisation with Numerical Weather Models: the ALiRA Project

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SUMMARY

The operating temperatures of overhead line (OHL) conductors dictate how much current can be safely passed through a line. Higher currents could lead to conductors exceeding their designed operating temperatures, or clearances being broken due to increased conductor sag. To manage and decrease risk, OHL circuits are therefore subject to static line ratings (otherwise known as post fault ratings) that ensure safe operation over the network. These ratings effectively limit the capacity of a given circuit to a maximum safe power flow, thus limiting the risk of overheating and asset damage.

Currently, static (post fault) line ratings are applied across the transmission network on a season-by-season basis, with fixed thresholds set across the whole network regardless of the geographical location of the assets. Moreover, line ratings are based on weather data from limited numbers of meteorological stations, which do not cover the full geographical and temporal variability of weather conditions across the network. This approach can impose conservative constraints to some routes, limiting power flow and forcing network operators to invest in unnecessary upgrades. In contrast, other routes may be deemed safe to accept additional power flow, while in fact running at higher than expected temperatures, thus risking disruption to the transmission of electricity.

The Advanced Line Rating Analysis (ALiRA) project is an NIA-funded innovation project (http://www.smarternetworks.org/project/nia_ngto014) developed by Digital Engineering (DE) in collaboration with National Grid Electricity Transmission (NGET) to improve their static (post fault) line ratings for the transmission network of England and Wales. Using 10 years of simulated weather data, DE calculated operating temperatures for all circuits on NGET's transmission network. The results of this work will enable NGET to maximise investment in additional transmission capacity where favourable weather yields lower thermal ratings, and to increase utilisation of the current assets while reducing risk of exceeding design operating temperatures.

This will enable NGET to accurately estimate risk on a span-by-span basis; to regulate power flow through circuits at highest risk and to unlock extra capacity through low-risk ones; and to prioritise upgrade and maintenance strategies, improving the overall resilience and reliability of their network.

KEYWORDS

Post-fault static line ratings; operating temperatures; overhead lines; numerical weather prediction; risk assessment.

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DATA AND SOFTWARE

Line Rating Code

DE adapted and improved upon existing software provided by NGET to calculate conductor operating temperatures (based on [1]). Several modifications were made to ensure compatibility with DE's numerical weather prediction (NWP) model and computing hardware. Additional changes were made to improve computational efficiency in view of the large volume of data to process (the project generated over 1 TB of data).

NGET provided 8 test cases to ensure these changes did not materially affect the numerical results. The test cases included 4 different conductor types and a range of currents (from 600 to 2000 Amps). All the test cases used the same input weather data, which ranged from worst-case scenarios of no wind and high solar irradiance, to best-case scenarios of high wind speeds perpendicular to the span and no solar irradiance. No significant differences were found between the results generated by the original and modified software.

Asset Data

The asset locations, elevation and circuit classification were provided by NGET to DE for over 21500 unique spans in England and Wales [2], covering a total network length of 7200 km (4474 miles). Data describing conductor physical properties was also provided for 10 different conductor types, to be analysed at each asset location. NGET also provided their 5 standard post-fault load cases, varying by season and for each conductor type.

Weather Observations

Weather observations from 11 masts were provided by NGET. Each mast covered a period of at least one year at a frequency of 10 minutes and included the weather variables necessary to calculate conductor line ratings (wind speed, wind direction, ambient temperature and solar radiation). The masts were mounted to OHL towers at 10m above ground level.

NUMERICAL WEATHER PREDICTION

NWP Model

Simulated high resolution weather data were generated for 10 years by DE using the WRF-ARW regional NWP model [3]. This was done using two-way nested simulations to 'downscale' global reanalysis data from a spatial grid size of around 55 km to 9 km, over an area covering Great Britain and Ireland. The global reanalysis data was generated by the NCEP Climate Forecast System (CFSR/CFS2 [4]). Time-series of all required weather variables were extracted at the location of each asset and at an elevation of 10 m above ground level, which was used as reference height for all operating temperature calculations.

NWP Data Post-Processing

To reduce biases in the near-surface temperature and wind speed predictions, NWP data was statistically post-processed using weather observations from 65 meteorological masts across England and Wales, extracted from NOAA's Integrated Surface Database [5]. As the distribution of temperatures is already well reproduced by the raw NWP model, only a small adjustment was made during post-processing, which increased the average temperature by 0.7 °C (1.3 °F). The adjustments made to the wind speed distribution are more significant and non-linear (Figure 1), which reflects the fact that wind speed is generally less well predicted than temperature by NWP models. Wind speeds from mast data below 1 m/s were not considered when fitting the distribution due to the presence of anomalous readings at very low wind speeds.

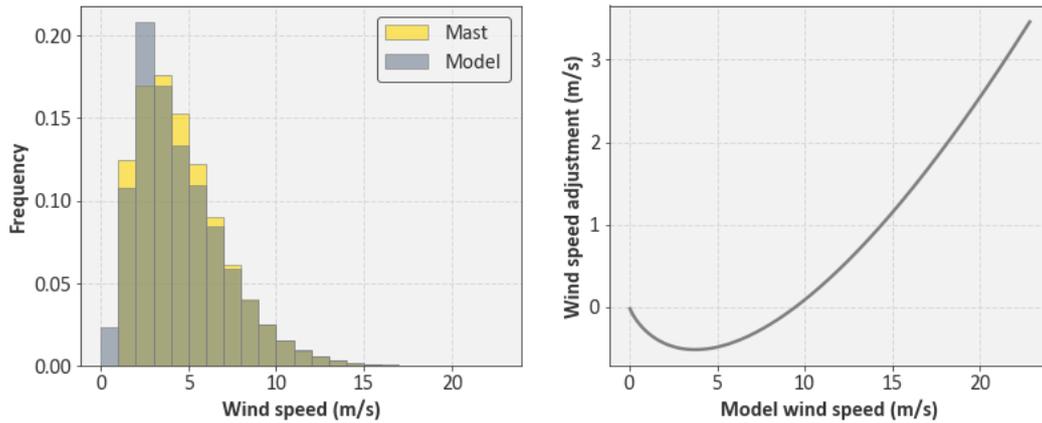


Figure 1: Adjustments to the raw NWP wind speeds made during post-processing. Mast data were cropped to wind speeds above 1 m/s. Left panel: wind speed distribution from mast data and NWP data for 65 masts in England and Wales. Right panel: the adjustment applied to the raw NWP wind speeds.

STATISTICAL TESTS

A wide range of statistical tests were performed to assess the impact of using NWP data to calculate operating temperatures, and to quantify the capabilities and limits of this approach. All tests were done using the raw NWP data, prior to the post-processing outlined above.

Sensitivity to Resolution

Different NWP resolutions were tested against the weather mast data provided by NGET, to determine the optimal balance between spatial resolution and computing costs and times. Operating temperatures were calculated using data from the weather masts and compared to the same results obtained using NWP data at 9 km and 3 km resolution ('medium' and 'high' resolution, respectively).

The operating temperatures from these tests showed no statistically significant difference (for instance, one case showed an average operating temperature difference of 0.8 ± 2.5 °C or 1.4 ± 4.5 °F).

Therefore, DE used medium (9 km) resolution data throughout this study, as no significant improvement was found using higher resolution simulations.

Sensitivity to Time Period

To assess whether shorter time-series of data are adequate for the purpose of this study, operating temperatures were calculated at the weather mast locations using NWP data from both the full 10-year simulation and separate simulations covering the same period as the actual mast observations.

The results highlight a wide inter-yearly variation in operating temperatures and show that operating temperatures calculated using a single year of data cannot be assumed to be representative of the long-term trends. Therefore, DE used the full 10 years of simulated data in this study.

Uncertainty Analysis

DE investigated the potential effect of residual local biases in the NWP data on the predicted operating temperatures, by comparing the operating temperatures obtained at the weather mast locations using NWP and real weather data. The difference between the results was found to vary from location to location, with some masts showing good agreement and others revealing larger discrepancies. Where the NWP data underpredicted with respect to the real data, local features too small to be resolved by the model (patches of forestry or buildings close to the masts) were considered to be the most likely causes.

The range of uncertainty varies with conductor type, load case and chosen PoE, with the largest differences (up to 23 °C or 42.3 °F) observed for the 12% PoE and progressively decreasing towards lower PoE. This is due to the reduced cooling effect of wind at lower wind speeds, which characterise these low probability events.

RESULTS

Following the post-processing and tests outlined in the sections above, DE calculated operating temperatures for all conductors, load cases and PoE across the whole network operated by NGET.

Geographical Variation across the Network

The operating temperatures were found to vary widely across the network, as shown in the histogram in Figure 2 with a range of several tens of degrees Celsius (32 °C/58 °F in this particular example):

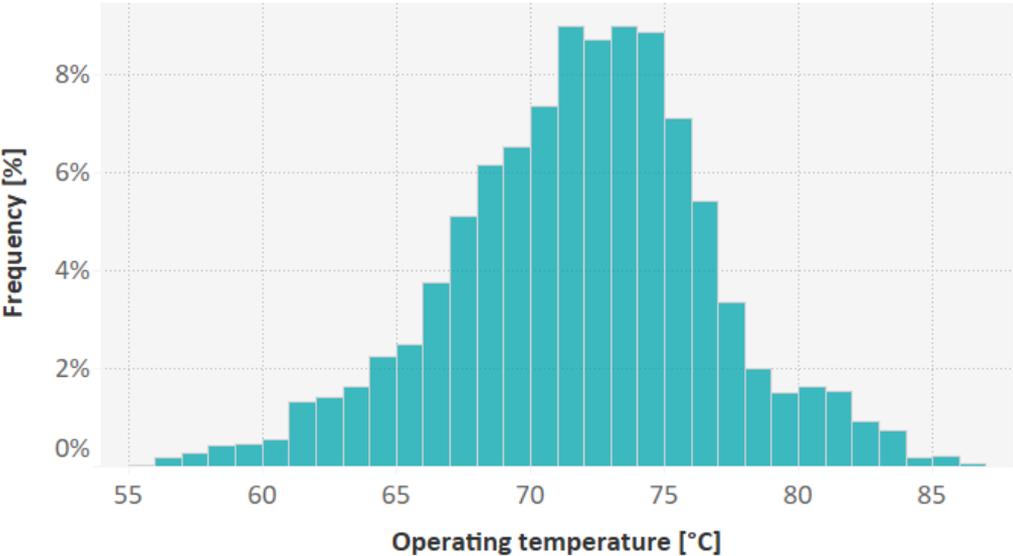


Figure 2: Operating temperatures across the network for an example of conductor and load case.

For a span of 300 m length (the average length of OHL spans in NGET’s transmission network) over level ground, this temperature difference converts to a 1.2 m change in clearance. This shows how an accurate estimate of operating temperatures at span level can provide useful insight for planning and maintenance purposes.

The same data can be visualised on a map (Figure 3) to show how the weather patterns and geographical distribution of assets affects their operating temperatures.

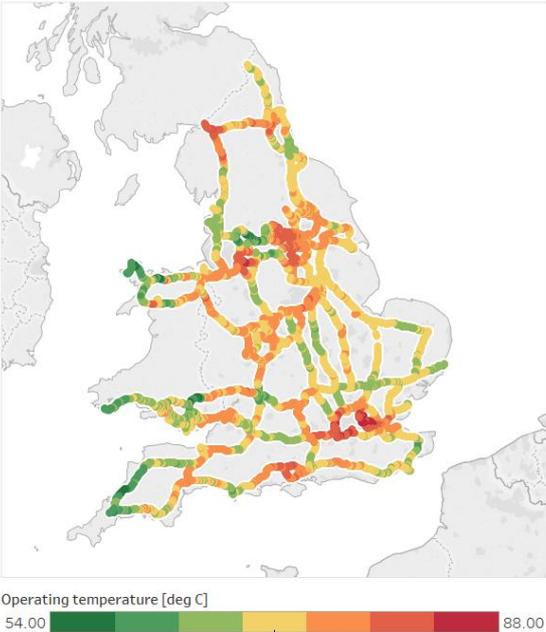


Figure 3: Map of operating temperatures across the network for an example conductor and load case, showing the wide range of variation as a function of geographical location.

The map shows that routes in coastal areas tend to exhibit lower operating temperatures on average than inland routes. Examining the weather variables for these routes, wind speed was found to drive the low operating temperatures in these situations, consistent with coastal routes being naturally more exposed to higher wind speeds. This is particularly evident along the west and southwest coasts, where some of the routes with the lowest operating temperatures are found. Conversely, air temperature is found to be a weaker driver of operating temperature than wind speed over the routes considered. Routes in coastal areas are therefore identified as the sections of the network with the highest potential for uprating. This may be relevant, for instance, for circuits connecting to offshore wind farms, which being at least in part in coastal areas will show a greater potential for uprating.

In-Route Variation

Exceedance temperatures were also analysed in detail along selected routes. Operating temperatures at different PoE for one example route are shown in Figure 4. At the most extreme PoE (0.1%), operating temperatures are determined by uncommon combinations of low wind speed, high ambient temperature and high solar irradiance. These extremely calm conditions result in lower variability in operating temperature along the route (the standard deviation being 1.6 °C or 2.9 °F), as wind speed is negligible, whilst air temperature and solar irradiance tend to vary over larger spatial scales than wind. Conversely, the less extreme PoE events are driven by a broader range of wind speeds and thus show wider variation from span to span (standard deviation of 5.6 °C or 10.1 °F for the 12% PoE case).

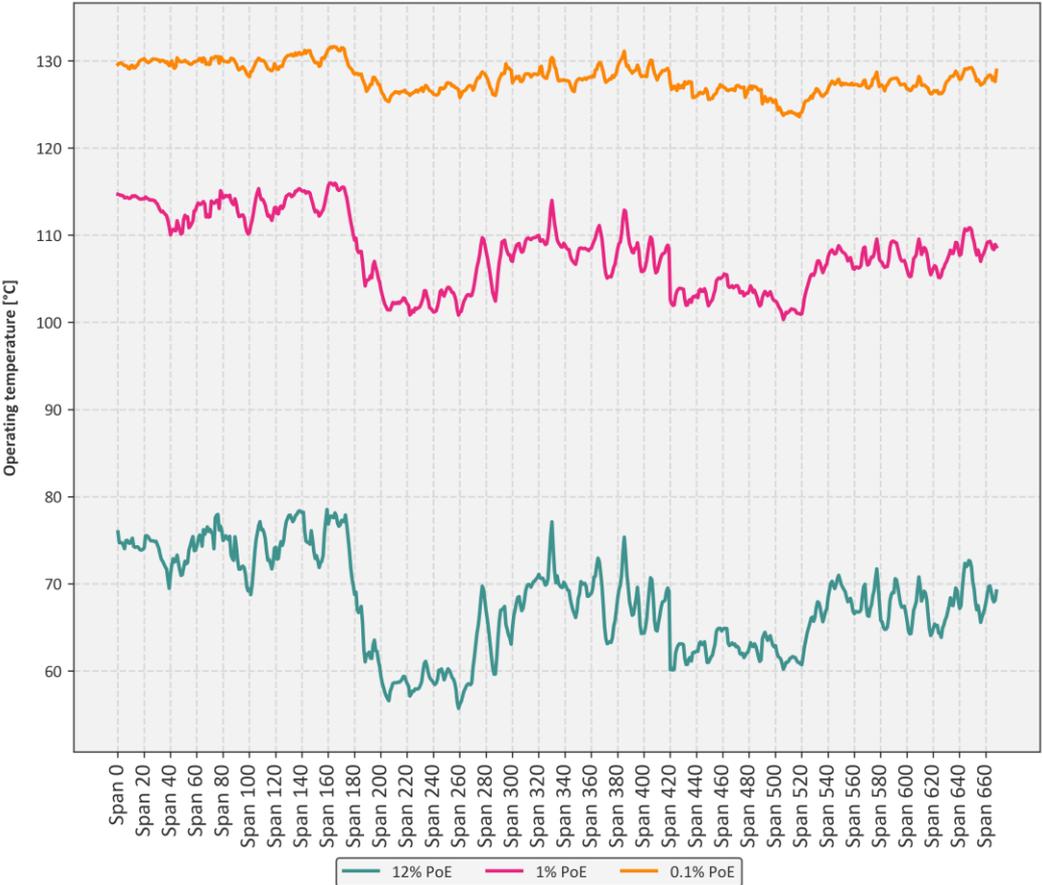


Figure 4: Operating temperatures at different PoE for an example circuit, highlighting the varying range of variation at different thresholds.

A comparison of two example routes with very different thermal profiles is shown in Figure 5, where the effects of weather variations and terrain elevation result in two very different regimes in terms of both the circuit-average operating temperature and the span-by-span variation. The first circuit shows high temperatures throughout (average of 79.5 °C or 175.1 °F), with relatively small and gentle variations from span to span (2.5 °C/4.5 °F standard deviation). The second circuit shows overall

lower average operating temperatures (67.7 °C/153.9 °F), with much wider and more rapid span-to-span variations (5.6 °C/10.1 °F standard deviation). This is due to the presence rapid changes in terrain elevation, which exerts a large effect on the ambient wind speed.

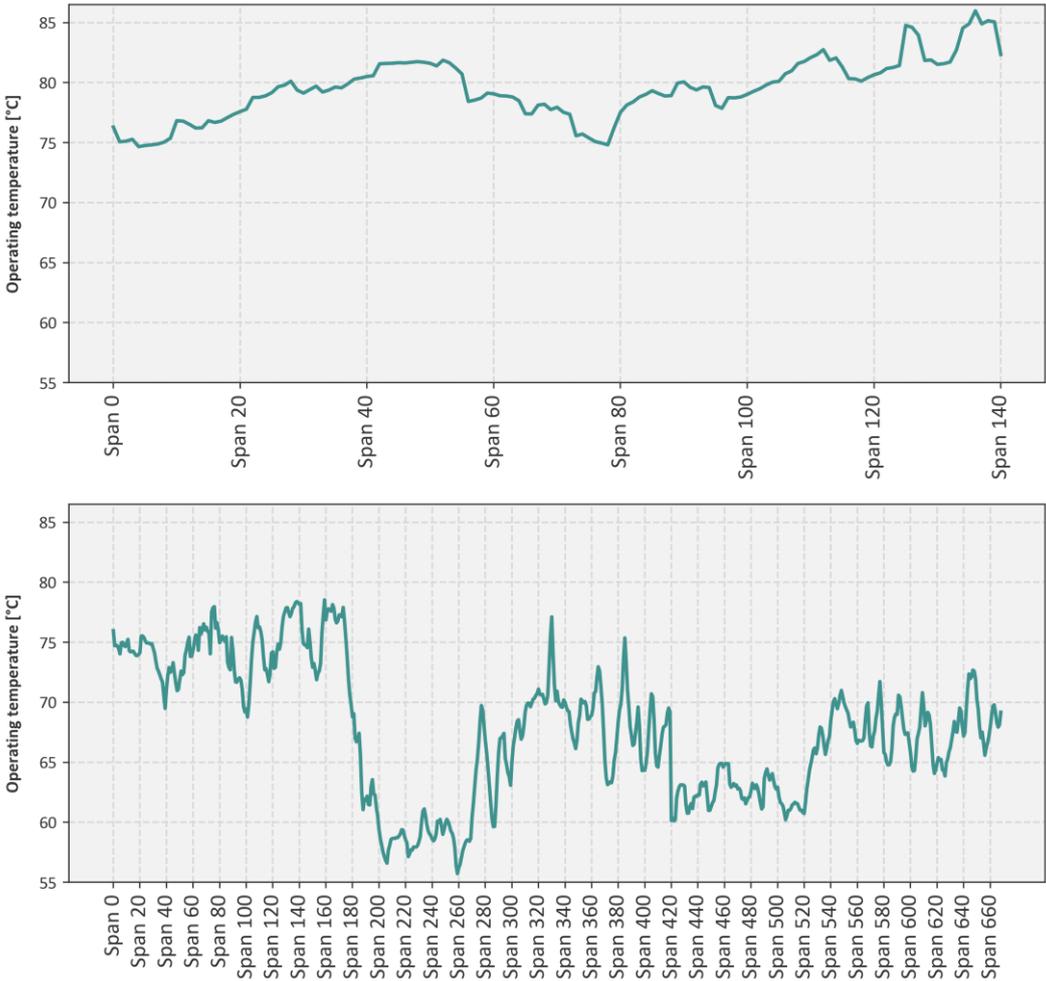


Figure 5: Two examples of circuits with very different behaviours and patterns. Top panel: a circuit in the NE of England. Bottom panel: a circuit in the SW of England.

These two examples demonstrate both the impact of large-scale regional patterns on different routes, which manifests as different operating temperature averages and ranges across the route; as well as small-scale local effects on individual spans within a circuit, due to terrain changes and other local features.

CONCLUSIONS

The ALiRA project has demonstrated the value of assessing operating temperatures at span-specific locations using NWP data to capture the geographic variability due to weather. By highlighting areas that are less prone to adverse weather conditions, for example in the southwest of England and Wales, NGET may make informed decisions about the up-rating potential of individual circuits. This may help to unlock extra capacity in the existing transmission network, without the need for reconductoring or the construction of new transmission lines, resulting in lower costs for consumers.

FUTURE WORK

A preliminary investigation into how seasonal load changes affect operating temperatures suggests there is potential for improved definitions of seasons for line rating purposes. This is demonstrated in

Figure 6, which suggests that, on average, the peak operating temperatures occurred in September during the 10-year period of this study. This is caused by an increased load current combined with relatively low wind speeds (when compared to October and November). This diagram is based on average monthly operating temperatures for a total of 15 randomly selected spans. This result suggests that the seasonal PoE operating temperatures do not necessarily follow a simple seasonal cycle, as is currently assumed. More work is needed to investigate this, including analysis of many more years of weather data to reliably determine the long-term seasonal trend. A complete analysis of this behaviour by geographical area may allow NGET to optimise seasonal rating strategies, ensuring that the transmission system is utilised to its full capacity throughout the year.

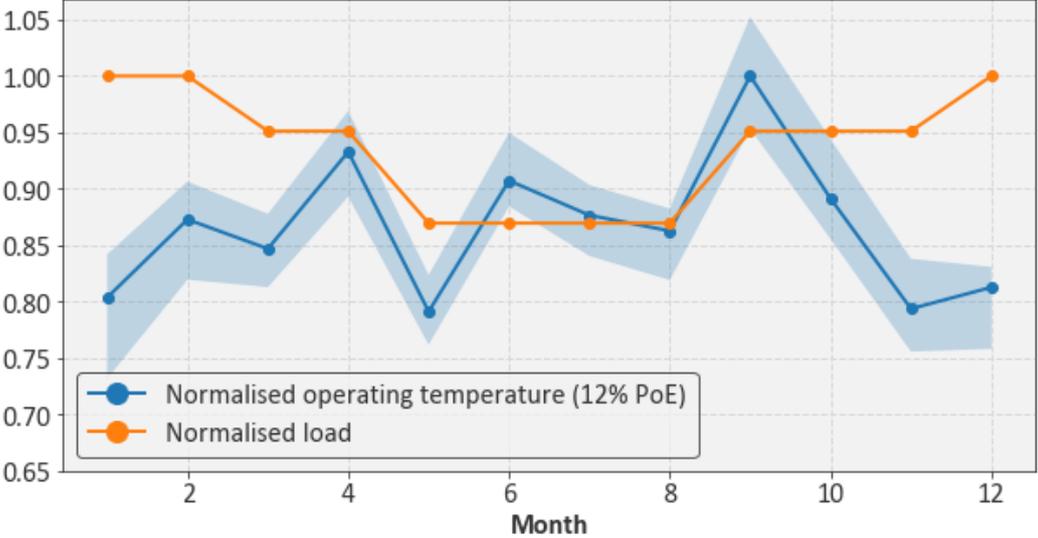


Figure 6: Seasonal load change and average operating temperature for 15 randomly selected assets.

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