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Recent Overhead Transmission Line Technology and Environmental Measures

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Reducing Low Carbon Generation Curtailment with Dynamic Line Ratings on the England and Wales Transmission System

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SUMMARY

Driven by a mission of achieving a net zero grid by 2035, National Grid is using innovative technology as a means to more efficiently operate the transmission grid. Dynamic Line Rating (DLR) represents one important method for maximising the capacity of existing infrastructure. Dynamic Line Rating sensors have been utilised to increase capacity on a critical 275 kV line carrying low carbon power to consumers. This line is regularly congested and significantly limits flows during planned outages on the transmission system. In 2021, an estimated £808 million [1] was spent curtailing low-carbon electricity due to insufficient capacity on the Great Britain transmission grid. The DLR project outlined in this paper has unlocked nearly 1 GW of additional capacity on a critical transmission double circuit.

This paper evaluates the observed capacity increases and key trends based on the DLR installation across seasons, months, days, and hours. The DLR profile and the low carbon generation profile correlate, indicating that capacity is available at the same time it is needed. With hourly DLR updates, a capacity increase of 29-33% is possible. A simplified operational implementation of DLR with daily updates achieves a 9% increase in circuit capacity on the line, creating an uplift in boundary capacity of 19%. Based on this uplift, 2022 savings on a critical boundary, SSHARN boundary B7a, would have been approximately £14.25m by preventing curtailment and improving flexibility of grid operations. These savings are essential in delivering a fair and affordable transition to net zero for the UK power system by 2035.

Furthermore, the magnitude of enhancements achieved throughout the DLR study are assessed to understand the potential for accelerating additional renewable connections to the transmission grid. Congestion related to generation interconnections to transmission grids is limited by the speed at which the network capacity can be expanded and reinforced to support the anticipated generation or demand. Traditional reinforcement works require complex, long-duration system outages as well as significant consenting works to agree access with registered landowners. This type of work takes up to five years to complete, whereas DLR can be deployed in less than a year due to the size and required penetration of DLR sensors.

KEYWORDS

Dynamic Line Rating - DLR - Transmission Line Monitoring - Curtailment - Wind Generation

1. National Grid's Dynamic Line Rating Installation

DLR technology is utilised to increase capacity on the Kirkby – Penwortham – Washway Farm circuit. This is a circuit which under pre-studied system conditions can be a bottleneck for high wind generation in the north of England & Scotland. Moray East wind farm in Scotland was recently commissioned in August 2022 with a rated capacity of 950 MW. This is a trend set to increase as the UK drives to 50 GW of offshore wind by 2030. In January 2022, 24.8 GW of offshore capacity was announced by Crown Estate Scotland. With wind generation connecting to the system rapidly, an intermediate solution was required to deliver capacity on the transmission network before larger strategic works could be implemented.

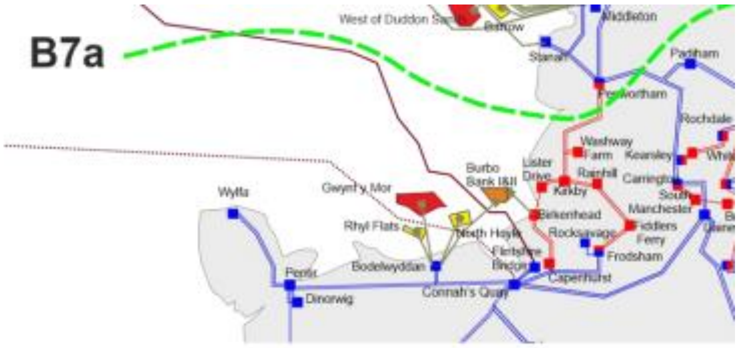


Figure 1. Key wind generation area north of England Picasso at the B7a boundary

The B7a boundary, which the Kirkby-Penwortham-Washway Farm intersects, is described by the Electrical System Operator (ESO) prior to the DLR installation as being limited to a capacity of 9.4 GW due to a thermal constraint on the Penwortham – Washway Farm 275 kV circuit [2]. This 9.4 GW is a theoretical thermal maximum with the usual boundary capacity being lower due to voltage stability concerns.

Outages on either the Kirkby – Penwortham – Washway Farm circuit number 1 or 2 in January 2021 were shown to have reduced the operational boundary capacity of B7a from 6700 MW to 4900 MW, a reduction of 1800 MW [3]. This results in two undesirable scenarios for the electricity consumer:

1. The outage required to maintain critical national infrastructure is deferred, increasing the risk of asset failure and resulting in the potential loss of electricity supply.
2. The outage proceeds resulting in the potential for significant constraint costs.

Outages on this circuit have been historically requested for an average of 14 days per year. Previous studies have identified a generation background of up to 6400 MW with a boundary capacity of 4900 MW. The 14-day outage then could have a worst-case exposure cost of £75.6m. Assuming that the generation background is achieved 25% of the time due to high wind, there would be a forecasted constraint cost of £19.1m without any circuit enhancements.

To address this thermal constraint, we installed 11 sensors to fully equip the Kirkby – Penwortham – Washway Farm double circuit line for DLR. DLR is calculated for each section of the line and the minimum rating across all sections is reported as the line rating. The sensors were installed in August 2022 and data has been collected through the autumn, winter, and spring seasons.

Four individual DLR values are provided, one for either side of the double circuit both north and south of Penwortham Substation. The DLRs across the four lines are not necessarily the same as they are based on local conditions and sensor data. Line orientation, or heading, has a significant impact since parallel wind does not provide as much convection cooling as perpendicular wind. The analysis in this paper is based on one representative transmission line.

2. Dynamic Line Rating Methodology

Existing overhead lines are rated based on the Maximum Operating Temperature (MOT) and capacity is typically calculated based on conservative seasonal assumptions of solar gain, ambient temperature, and wind speed. These assumptions are necessary to ensure the safe operation of the transmission system in the absence of any real-time live data. Existing transmission infrastructure often has unrealized capacity due to these conservative assumptions and may be operated more efficiently with more granular spatial and environmental data.

Dynamic Line Ratings (DLRs) are calculated using sensor-validated weather parameters including solar irradiance, ambient temperature, and wind speed and direction. Effective wind speed is the most influential variable in the line rating heat balance calculation, therefore factoring wind into a real-time dynamic rating of an overhead line can unlock significant capacity.

The DLR model is built and trained on a combination of weather and sensor data. Scanning optical LiDAR sensors are installed on towers at strategic locations to continuously measure the position of the conductor. This information is then combined with atmospheric weather information, line loading data, and conductor properties to train and validate a Computational Fluid Dynamics (CFD) model. CFD calculates the cooling effect of wind on each span based on conductor position, terrain, and sheltering from vegetation and buildings. The CFD model is then validated by sensor data in two ways: conductor blowout of the monitored span, and conductor temperature of the monitored section.

This allows for utilisation of enhanced capacity on lines based on actual weather conditions without exceeding the conductor's maximum operating temperature. The DLR unlocks additional capacity on the grid, directly reducing congestion and curtailment challenges.

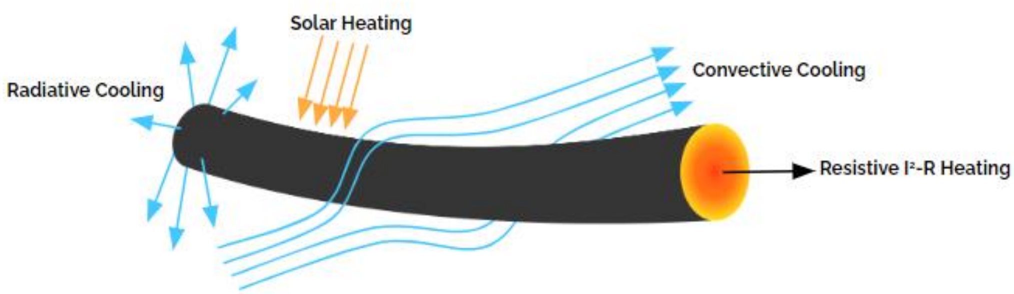


Figure 2. IEEE 738 heat balance heating and cooling components [4]

3. Hourly Dynamic Line Rating Results on Kirkby – Penwortham – Washway Farm

In Table 1, hourly Dynamic Line Ratings for one transmission line are compared to the post-fault seasonal static ratings. Additional capacity across the system boundary may be calculated by doubling these values to account for the double circuit. Capacity is needed only in post-fault scenarios on our system when one or more adjacent transmission lines are out of service for maintenance, so DLRs are compared to post-fault seasonal static ratings. Note that data has not yet been collected through the summer months.

Table 1. Hourly Dynamic Line Rating Statistics

	Autumn Sep – Nov	**Winter Dec - Feb**	**Spring Mar - Apr**
Static Post Fault Rating	3068 A	3194 A	3068 A
Average Capacity Increase	1020 A (486 MVA)	939 A (447 MVA)	956 A (455 MVA)
Average % Capacity Increase	33%	29%	31%
% of Time DLR > Static	97.5%	96.8%	97.4%
% of Time DLR > Static+5%	94.8%	91.9%	93.9%
% of Time DLR > Static+10%	90.8%	83.6%	88.2%

Hourly average DLRs are summarised in the heat map below, with each cell representing the average DLR value for the given hour of the day across all days in the month. Data has not yet been collected through the summer months.

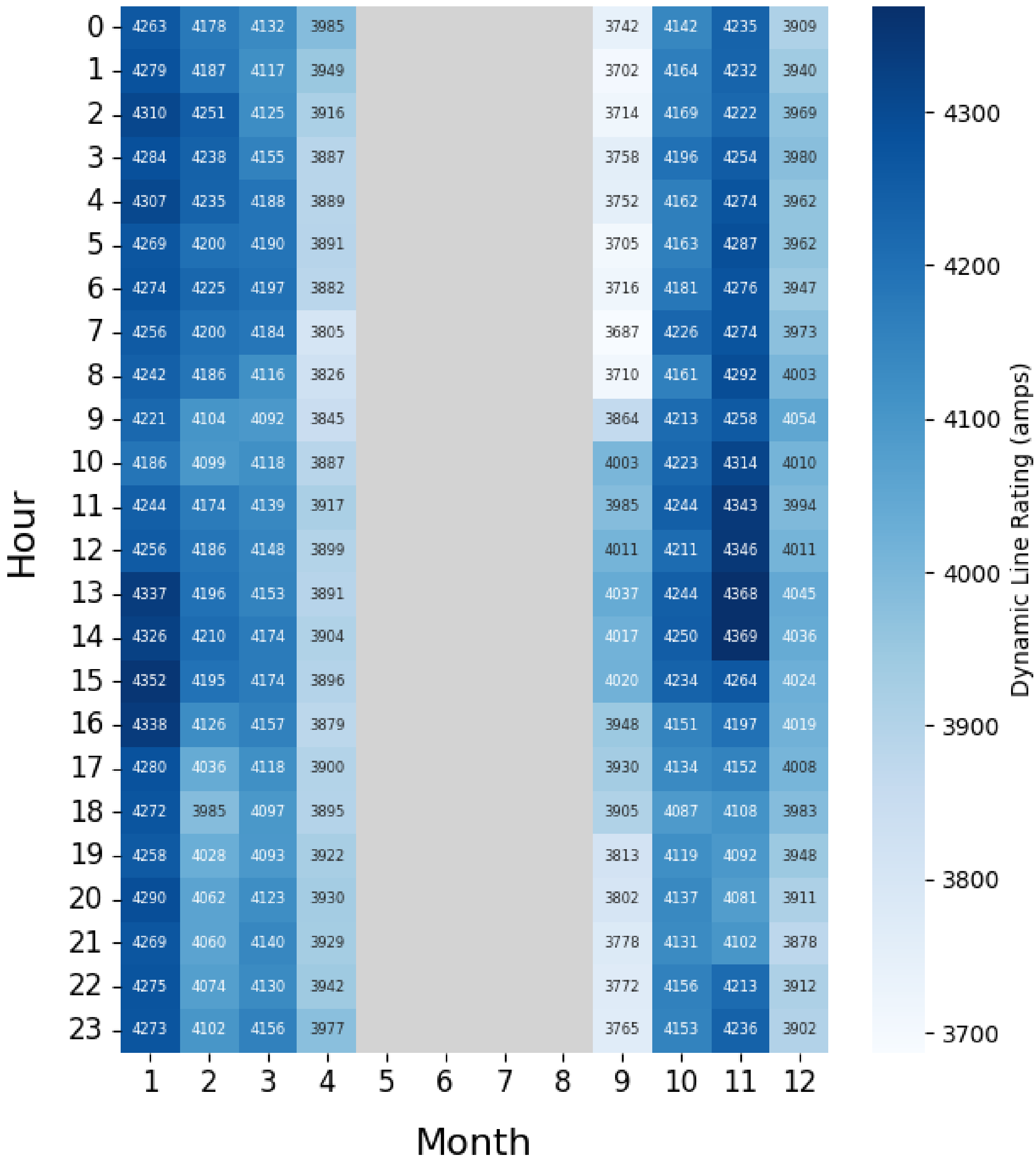
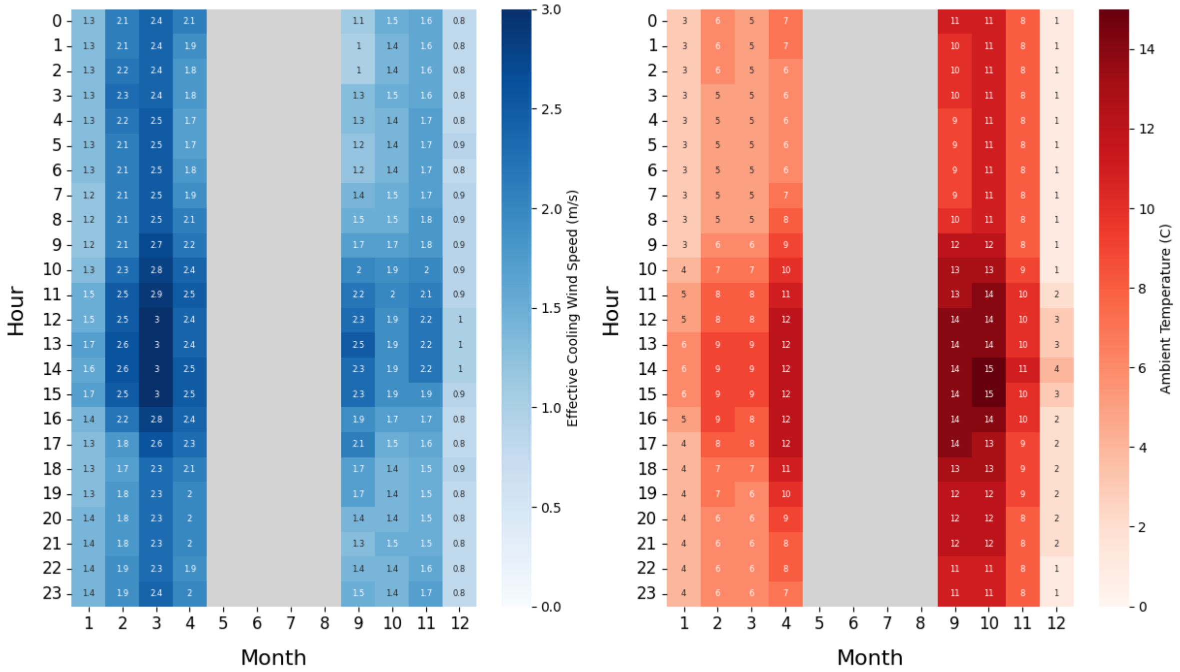


Figure 3. Average hourly DLR

Trends in average hourly DLR are driven strongly by wind. Effective cooling wind speed is the perpendicular wind speed which yields the same convection cooling as the actual wind speed and direction [5]. Ambient temperature also impacts ratings, though typically to a lesser extent than wind. Seasonal and daily trends in effective cooling wind speed and ambient temperature are shown in Figures 4 & 5. Data has not yet been collected through the summer months.



Figures 4&5. Average hourly effective cooling wind speed and ambient temperature of the limiting site

Percent average capacity increase of DLR over seasonal static ratings is shown below. With an hourly DLR implementation, average hourly capacity increases of 20-42% are achieved throughout the year.

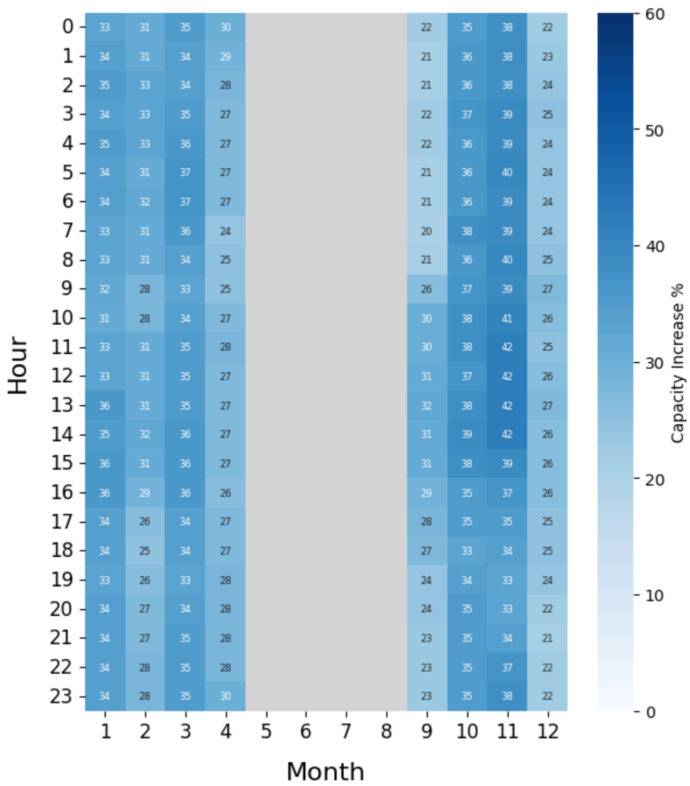


Figure 6. Average hourly percent capacity increase of line-level DLR over static

4. National Grid’s Operational Implementation of Sensor-Based Dynamic Line Ratings

The focus of DLR efforts and analysis has been on the Penwortham-Washway Farm leg of the circuit as this section has had the lowest average uplift in capacity.

Whilst the DLR technology allows for ratings to be issued every hour, currently the technology is used in a forecasting mode, picking out the lowest value at 6 AM day-ahead and issuing a new 24-hour dynamic rating based on the lowest forecasted rating across the coming day. This gives us the ability to create a new higher limit for the boundary, opening more capacity for intermittent renewable generation.

For this project, we are operating with a 50% exceedance risk. Without other limiting elements, this would in theory result in the overhead line operating beyond its rated temperature 50% of the time if it was operating at the full post-fault continuous rating. During operation, however, the overhead line enhancement is limited by the capacity of other power electronic assets on the circuit. Whilst these assets can be enhanced using ambient temperature assumptions, the scope for significant enhancements (over 250 MVA) is reduced, limiting the maximum operating temperature of the conductor to within our policy. For reference, this overhead line historically has been operated with a percent exceedance risk of 12%.

When analysing 5 months of operational data (24 hour ahead forecasted ratings accounting for the next limiting factor) we observed an average increase of 300 A (9.4%) over the static rating in winter and a 276 A (9.0%) increase over the static rating in autumn and spring.

The uplift in capacity from this approach can create significant savings for electricity consumers. Modelling has shown that for a 28-day outage, during January 2021 the thermal generation mix would have resulted in constraint costs during periods of high wind generation.

Table 2. Cost of outages to SSHARN3 with and without Dynamic Line Ratings

% of time NETS sees high wind generation above capacity	Cost of a 4-week outage (28 days) without DLR	Estimated DLR savings	Percentage cost reduction from installing DLR
5%	£7.64m	£1.44m	19%
25%	£38.18m	£7.2m	19%
50%	£76.36m	£14.4m	19%

Wind generation is inherently intermittent, and the generation output is difficult to forecast in the medium to long term. However, when applying DLR to the model, we see an average circuit capacity increase of 300 A (142.9 MVA) during January. Given the circuit is the limiting factor on the SSHARN boundary, this results in an operational boundary increase in capacity of 285.8 MVA.

5. Dynamic Line Ratings and Wind Generation

Average hourly wind generation of seven nearby onshore and offshore wind generation facilities which most directly impact the Kirkby – Penwortham – Washway Farm line are summarised below. Generation is greatest when wind is strong, correlating well with DLR capacity increases.

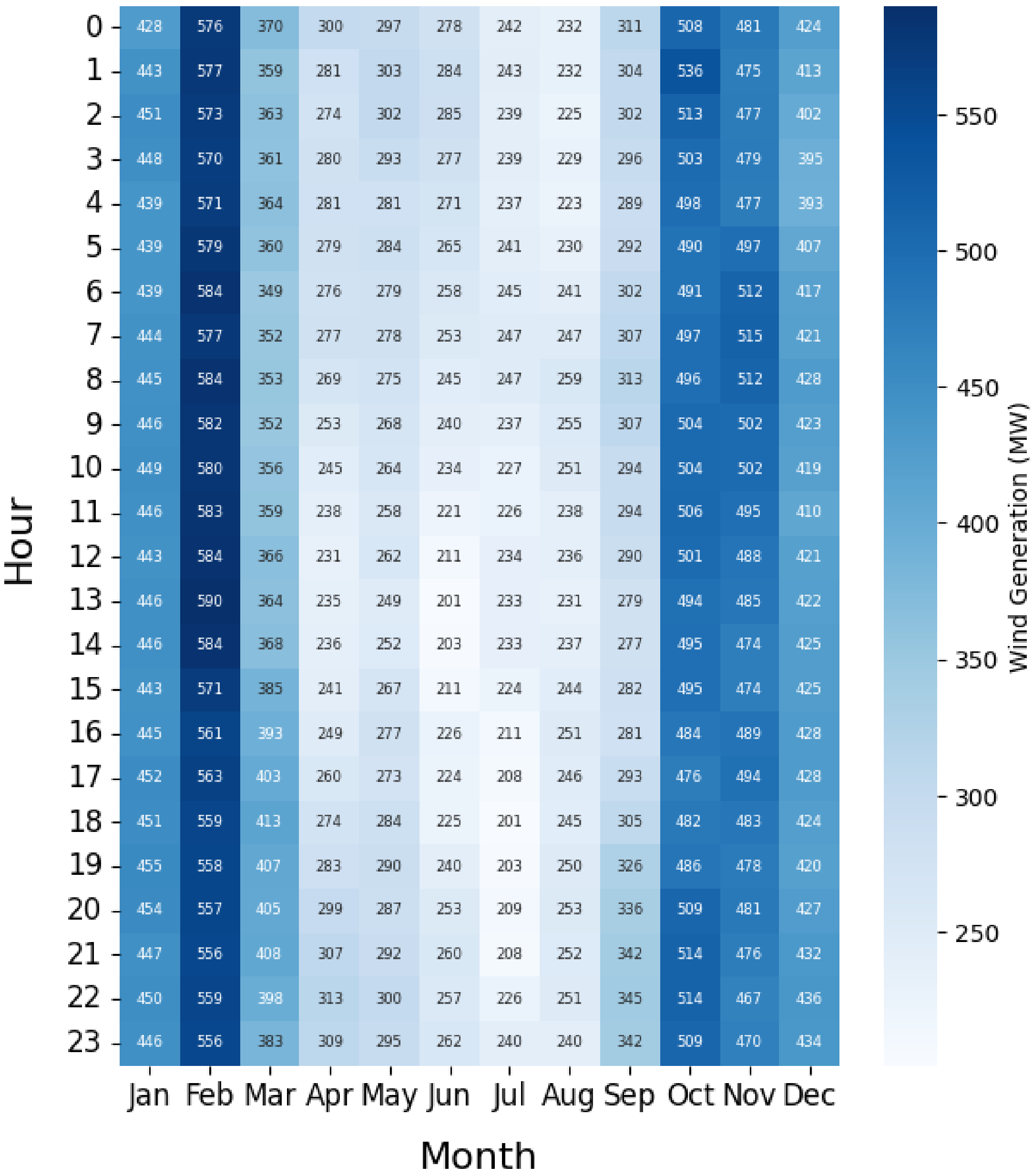


Figure 7. Total wind power (MW) during the settlement period

The positive correlation between wind generation and DLR is illustrated in Figure 8. DLR on this chart reflects the daily operational implementation with no floor or ceiling applied. Additional capacity may be unlocked by using DLR with an hourly implementation.

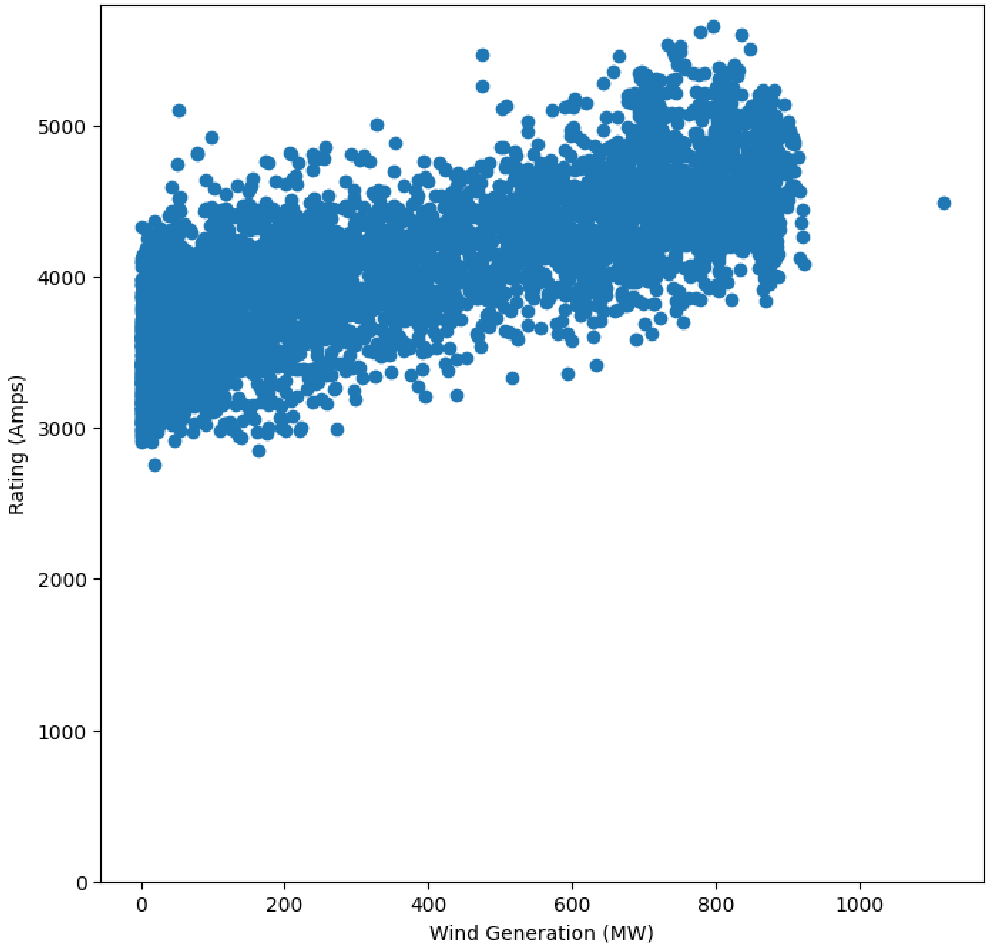


Figure 8. Daily Dynamic Line Rating vs hourly wind generation

6. Opportunity for System-Wide National Grid Implementation of Dynamic Line Ratings

Given the benefits calculated for an installation on a single overhead line, there obviously remains significant potential for even more benefits should the devices be installed system-wide. Thermal constraint costs (costs that are associated with the insufficient capacity of overhead lines) in England & Wales are increasing because of the additional generation connecting to the transmission network. In 2021, constraint costs in England & Wales totalled £270m, in 2022 these totalled £418m [6].

With the transition to net zero, we will be required to maximise system access on the transmission system in order to accelerate critical network reinforcements and renewable energy connections. By maximising the number of outages there will be an inherent increase in associated constraint costs. This short-term increase in cost could be significant but is entirely necessary if the UK is to reach its net zero ambitions.

As this trial on the Kirkby – Penwortham – Washway Farm circuit has shown, a way of blunting the short-term spike in constraint costs could be the use of DLR on overhead lines.

Looking at the SSHARN boundary (B7a), the boundary crosses 4 double circuits with a total combined length of 262km of overhead line. Based on a boundary increase in capacity of 19%, savings on this boundary in 2022 would have been approximately £14.25m.

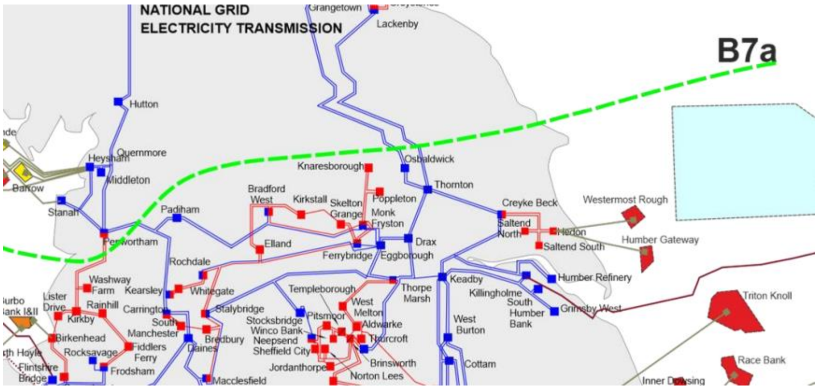


Figure 9. SSHARN (B7a) Boundary

7. Further Potential Benefits of Dynamic Line Rating Expansion

Along with the financial consumer benefits presented previously, there are potential wide-ranging benefits for transmission owners that could be accomplished with a wider national rollout.

The first benefit is the potential to accelerate new renewable energy customer connections onto the transmission grid. A significant number of generation connections on transmission networks are delayed as a result of the network requiring additional reinforcements before a firm connection can be supplied to the customer. However, given that DLR technology could be applied non-outage, the enhancements provided could enable smaller-scale generation to connect on a non-firm basis, raising the generator output limit to the calculated overhead line capacity unlocked by DLR.

Further benefits could be achieved in the sense of transmission system security. In 2022, the UK recorded its highest temperature at 40.3 ºC. Overhead line ratings during this period assumed an ambient temperature of just 20 ºC. When some overhead lines on the transmission grid have a rated operating temperature of 50 ºC, such high ambient temperatures can lead to operating margin and safety concerns. DLRs, however, would allow us to view the real-time sag of a conductor in order to better manage the clearances along high-risk overhead line routes.

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CONCLUSION

In conclusion, installing DLR sensors on the Kirkby – Penwortham – Washway Farm circuit has led to significant increases in operational capability of our overhead lines whilst simultaneously improving asset visibility. DLR provides an average percent increase in capacity of 29-33% if ratings are updated hourly. When considering the next-limiting element of the transmission circuit, which limits extreme DLR enhancements, the average increase in capacity of the overhead line was over 9% even with a conservative daily implementation. Additional capacity increases may be realised with integration, which would enable the ingestion of hourly ratings.

This paper has also highlighted the potential benefits available with a wider rollout of this DLR technology. Along with the substantial thermal constraint cost reductions, there remain opportunities for improved intelligence on our assets to better secure the transmission system as well as improve our resilience against the ongoing effects of climate change.

(End of text)

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