Methodology Development for Weather Rating Evaluations
SIF REVISE ALPHA WP 6

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Placeholder Section

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1 Executive Summary

This report implements the developed line rating weather-dependent methodology based on CIGRE/IEEE line rating weather models developed in an earlier work package. It is applied to two transmission line sites, Hawarden and Kinloss, and uses weather data sourced from the UK Met Office from nearby weather stations. The analysis focuses on comparing line rating evaluations using the methodology with TGN26 exceedance levels, CIGRE evaluated fixed weather parameters and seasonal fixed weather parameters, as well as the average current load on the transmission lines. The report also evaluates line rating analytical estimations during daytime and nighttime periods and quantifies the analytical headroom between the analytical line rating (ALR) and seasonal fixed thresholds.

The main aims of the report are as follows:

- Demonstrate and implement the developed line rating calculations methodology developed in WP2/6 on the respective prototype conductors identified by National Grid and SSEN, respectively.
- Assess the line rating with CIGRE fixed weather parameters evaluated ratings and TGN26 ratings
- Evaluate the methodology for the transmission lines located near Kinloss and Hawarden sites
- Assess the line rating evaluations of day time and night time in the different sites for the associated conductors.

The developed approach integrates dynamic heat balance equations, seasonal adjustments and solar gain to calculate line rating weather ratings. Weather data is resampled at 30-minute intervals as outlined in the exceedance calculation standards. Seasonal fixed weather rating thresholds for winter, spring, summer, and autumn are extracted from TGN26 to account for environmental variability and to enable the identification of periods where line current ratings exceed these limits. Similarly CIGRE evaluated weather evaluated thresholds for seasons are also calculated,

The methodology shows that a modest line rating improvement e.g. 1-5% of present loads may be achieved both during the day and at night while remaining well within safety margins according to the thresholds considered. This would need to be evaluated in fault conditions where, for twin lines, a single line may carry up to twice its average normal load. The calculated line ratings always exceed static ratings in winter periods, thus potentially offering more headroom for load changes without exceeding limits during these times. Additional capacity in favorable weather conditions also appears to be possible. Analysis of day and night variations indicates modest but consistent increases in capacity possible at night. Recommendations on changing exceedance levels remain limited due to only two lines being evaluated in this study using nearby weather station location data. Recommendations for evaluating lines which have loads presently closer to TGN26 thresholds are suggested, as well as focusing on practical dynamic line rating evaluations to establish further knowledge for determining any recommended future TGN26 exceedance level revisions.

2 Introduction

This report outlines the methodology developed in Work Package 6, during which a line evaluation model was created by the University of Strathclyde. It provides an assessment of overhead transmission line ratings close to two key weather measurement locations in the UK: Hawarden and Kinloss. This assessment focuses on two different conductors: the 275 kV, 2x500 mm² Rubus AAAC (Twin Conductor) and the 132 kV, 1x300 mm² Upas AAAC cables, respectively.

The methodology integrates dynamic heat balance equations, seasonal adjustments, and solar gain to calculate effective fixed-weather ratings based on weather data provided. The data used was sourced from Work Package 4 conducted by the Met Office, which provided observed weather parameters for the Kinloss location in the North and the Hawarden location in the South. In this study, weather parameters were averaged over 30-minute intervals to smooth out spikes and reduce variations in detecting sudden environmental shifts. While many publications typically use a 10-minute interval due to its higher resolution, the 30-minute interval may be more suitable for a dataset covering 14 years [1],[2]. In addition, CIGRE recommendations for 20-30 minute evaluations appear appropriate to take into account thermal change evaluations.

Fixed weather parameters based on CIGRE recommendations were also analyzed and presented to show their values and effect on the calculated line rating. Fixed weather ratings do not change over time; they are calculated using conservative values for local weather conditions, such as wind speeds, solar irradiance, and the conductors' maximum temperature [2].

Seasonal fixed weather rating thresholds for winter, spring, summer, and autumn were extracted from the TGN(026) document to account for environmental variability and to identify periods when line current ratings exceed these limits. In contrast, analytical line ratings are derived from real-time environmental factors, including temperature, wind speed, irradiance, and humidity, using both CIGRE static ratings [3] and IEEE [4] Analytical dynamic evaluation methods. The dataset is also categorized into daytime and nighttime to assess the impact of solar gain and variations in ambient conditions. The implications of solar gain help to illustrate conductor operability and any potential for available load headroom.

The analysis compares traditional CIGRE Fixed Ratings with analytical Line Ratings (ALR) according to IEEE 738 standards. Seasonal thresholds for the Line Rating are established at 1200 A for winter, 1150 A for spring and autumn, and 1100 A for summer for the 132 kV, 1x300 mm² Upas AAAC conductor, which has a resistivity of 30.5 n·m. For the Hawarden site, the conductors used is the 275 kV, 2x500 mm² Rubus AAAC, also with a resistivity of 30.5 n·m. Each of the twin conductors is treated as an independent line to first approximation in the analysis below.

3 Methodology

This process involves calculating IEEE-based line ratings, CIGRE fixed-weather ratings and seasonal Fixed weather ratings and comparing these results with regulatory TGN(026) thresholds. The methodology is presented in the flow chart below in Fig. 3.1:

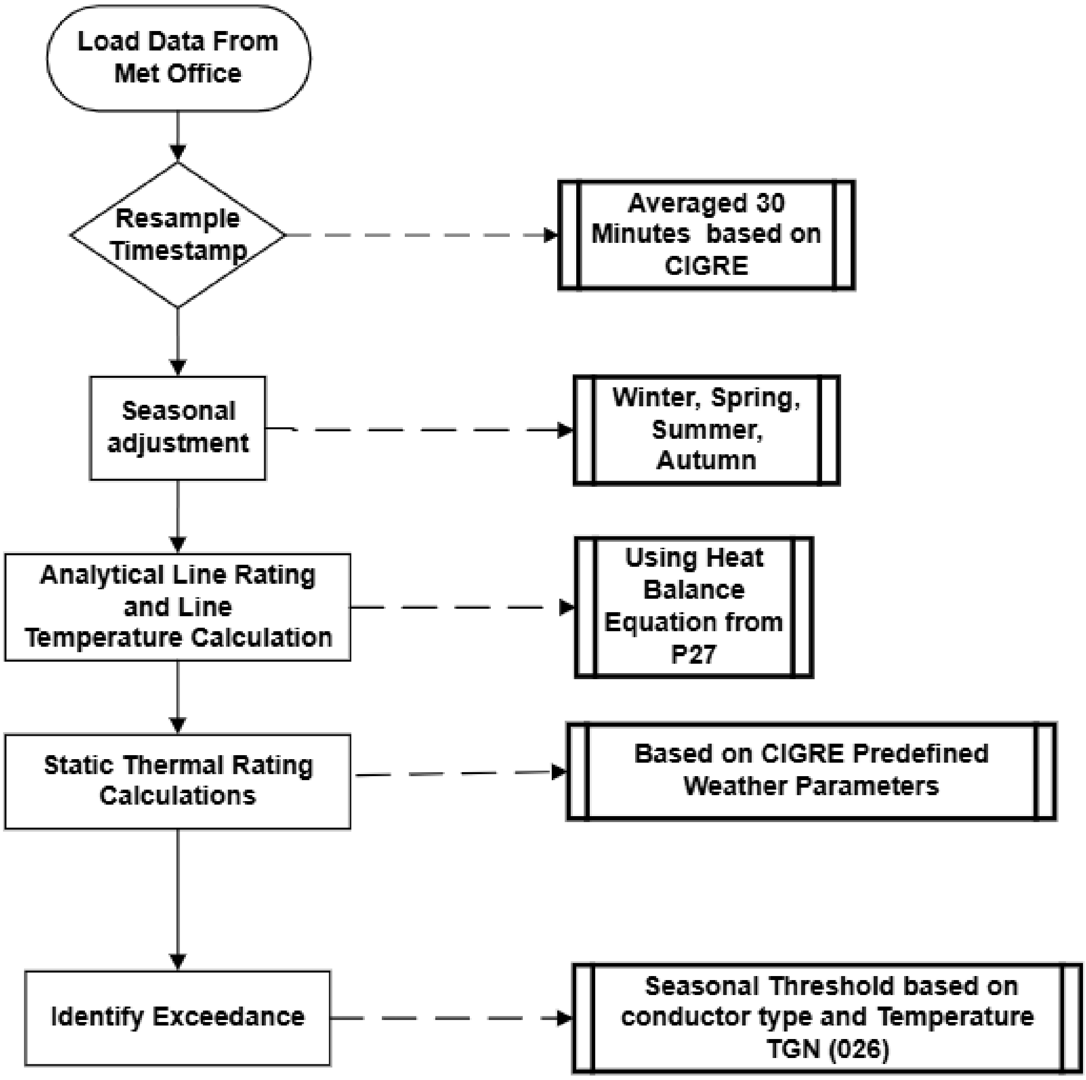

Figure 3.1: Methodology Flow chart

3.1 Load Weather Data

The critical inputs for the line rating calculations, such as temperature, wind speed, solar radiation and relative humity, were obtained from the Met Office as part of the Work Package.

3.2 Resample Timestamps

The obtained weather data is adjusted to an average of 30 minutes per CIGRE guidelines [3]. This guarantees uniformity and compatibility with the calculations, enhancing the precision of time-sensitive assessments.

3.3 Seasonal Adjustments

Seasonal adjustments are made to consider changes in environmental conditions, ensuring that the line ratings are suitably contextualized for various scenarios [3].

- Winter: Typically associated with lower temperatures, enhancing cooling.
- Spring and Autumn: Transitional periods with moderate environmental conditions.
- Summer: Characterized by higher temperature, which reduces cooling efficiency.

3.4 Line Rating and Conductor Temperature Calculations

Line ratings are calculated using the heat balance equation as stated and explained in the report of Work Package (WP 2/6) as:

$$I = \sqrt{\frac{q_c + q_r - q_s}{R\left(T_{\text{avg}}\right)}} \tag{3.1}$$

where:

I is the Line Rating of the Conductor
$R(T_avg)$is conductor resistance at average temperature
Q_{s} is the heat absorbed from solar radiation,
Q_{c} is the heat dissipated through convection, and
Q_{r} is the heat dissipated through radiation.

3.5 Analytical Line Rating

This is computed at each point derived using the IEEE 738 standard, which uses Analytical measured weather parameters:

- Ambient Temperature

- Wind Speed
- Solar Irradiance
- Relative Humidity

This method evaluates the conductor's heat balance and cooling capacity, yielding more realistic ampacity values.

3.6 Fixed weather Rating

Fixed weather ratings are calculated using fixed weather assumptions:

- Ambient Temperature: 20°C
- Wind Speed: 0.5 m/s
- Solar Irradiance: 800 W/m²

These conditions are conservative and aim to ensure safe operations year-round. These weather parameters are used in the heat balance equation to evaluate the line rating.

3.7 Seasonal Fixed Ratings

Based on the calendar month, seasonal ambient temperatures are defined as follows:

- Winter (Dec–Feb): 2°C
- Summer (Jun–Aug): 20°C
- Spring/Autumn (Mar–May, Sep–Nov): 9°C

For each season, a corresponding CIGRE fixed weather rating is calculated using the same method as for the fixed weather rating explained above.

The line ratings calculation methodology was supported and validated by the findings and data from the following publications, [5], [2] and [6]. These publications provide similar types of results as presented in this report.

3.8 Night and Day Variation

The amount of solar energy a transmission line absorbs varies between daytime and nighttime. Solar gain refers to the heat that a transmission line absorbs due to solar radiation. Since solar radiation is only present during the daytime, the solar gain at night is effectively zero. This means that during the night, other cooling factors, such as ambient temperature and wind, primarily influence the ratings of the transmission line. In this report, the Daytime is defined as the period from 9 AM to 3 PM, while nighttime is defined as the period from 10 PM to 4 AM. These values were recommended by the Met Office.

3.9 Potential Headroom Evaluation

Headroom used in the report refers to the extra current-carrying capacity available on a transmission line above the present load. It indicates how much additional current the line can potentially handle without exceeding its thermal limit [7]. The headroom calculation is given as:

$$\text{Headroom (\%)} = \left(\frac{\text{Line Rating} - \text{Load Current}}{\text{Line Rating}} \right) \times 100$$

It should be noted that the practical loading on the lines is designed to cope with fault scenarios, particularly if a twin conductor line is considered and that in faults, a single line is used for maintaining load in these circumstances.

4 Results and Observation

The following analysis of line ratings is presented under weather scenarios for the two transmission sites, Hawarden (275 kV Twin Rubus AAAC) and Kinloss (132 kV 1x300 mm² Upas AAAC), and spans over a decade (2010–2022) using 30-minute resolution weather data. The visualization on the plots is explained based on the following colour labels:

- Blue: IEEE Analytical Line Ratings (ALR), based on Met Office weather parameters
- Red dashed: CIGRE Fixed weather Line Ratings, calculated under conservative fixed conditions
- Green dashed-dot: CIGRE Seasonal Fixed Line Ratings, calculated for static seasonal conditions
- Black dotted: TGN(026) Thresholds, regulatory limits depending on season
- Magenta: Actual Load Currents, 500 A for Hawarden and 300 A for Kinloss

4.1 Hawarden

The conductor considered is the 275 kV Twin Rubus AAAC. It is important to note that when calculating a twin line with two parallel cables, the current is determined by dividing the resistance by 2, which effectively halves the current value as well as the TGN26 levels. [8].

The analytical line rating, calculated as the IEEE Analytical Line Rating (ALR, shown in blue), consistently surpasses both the Fixed Line Rating (FLR, represented by the red dashed line), Static Fixed Line Rating (SFLR, indicated by the green dashed line), and the TGN exceedance levels (TGN26, indicted by the dashed black line) as shown in 4.1.

This indicates the conductor can handle significantly more current than static assumptions imply in non-fault conditions. The variations arise from weather changes, with temperatures dropping to -10 degrees and wind speeds reaching 6 m/s, both of which are much higher than

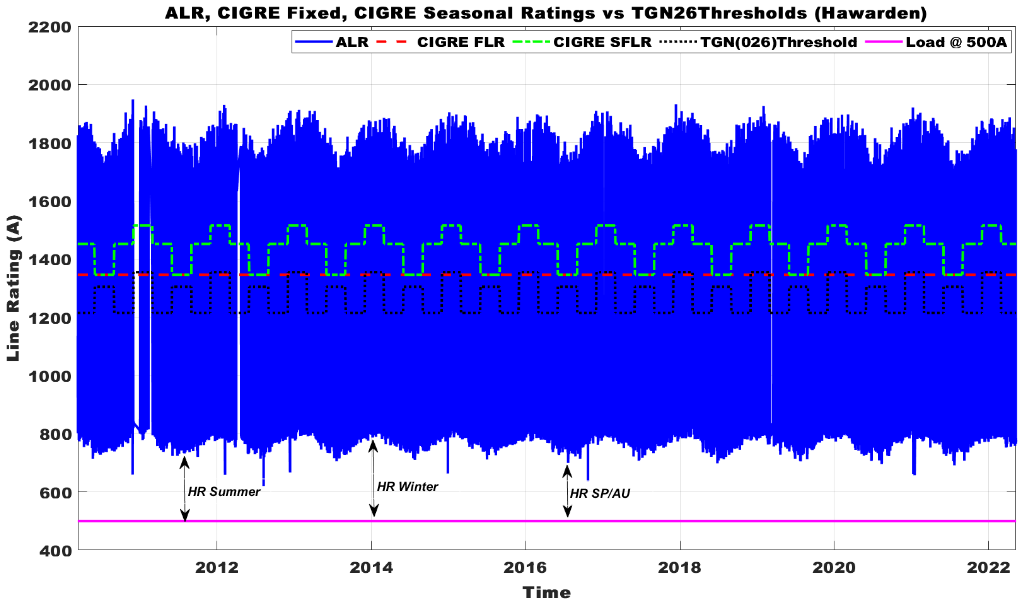

Figure 4.1: Time series Analysis of line rating in Hawarden

the conservative values used in fixed rating calculations. The ALR offers a more insightful assessment of line ratings based on weather conditions. The ALR stays above 1000 A, with a rare minimum of 512 A due to weather implications. It frequently approaches or exceeds 1900 A and can reach a maximum of 2008 A, indicating strong cooling conditions, particularly during winter. The TGN26 thresholds are exceeded in summer, meaning the line if the load was increased to these levels under these weather parameters could exceed the rated line temperature throughout the year. In terms of headroom on load, labeled "HR Summer," "HR SP/AU," and "HR Winter" illustrates the potential buffer between the load and the lower seasonal line ratings during those periods, all staying within a 1-5% limit. If the load was increased by 1%-5%, the line would, under fault scenarios carrying double the current, still be less than TGN and fixed line temperature values.

4.2 Kinloss

The conductor used is the 132 kV 1x300 mm² Upas AAAC with a load current of 300 A. The time series line rating analysis is shown in 4.2.

The Analytical ratings (blue) consistently exceed both the FLR (red), SFLR (green) values and the TGN26 values particularly through summer periods. The maximum rating reaches 1060 A, while the minimum is 314 A, with the FLR value recorded at 668 A. Seasonal variations are evident, with winter periods displaying higher ALR values due to cooler temperatures and increased wind. The 300 A load remains significantly below even the lowest ALR values, resulting in substantial available headroom (HR), which is over 20% in most cases if no additional fault dirrcted load is routed on this line. Seasonal headroom markers offer insight into the margin available under various climatic conditions. If actual current load was doubled it would exceed analytical line ratings in summer periods but this is not likely for a single line so there

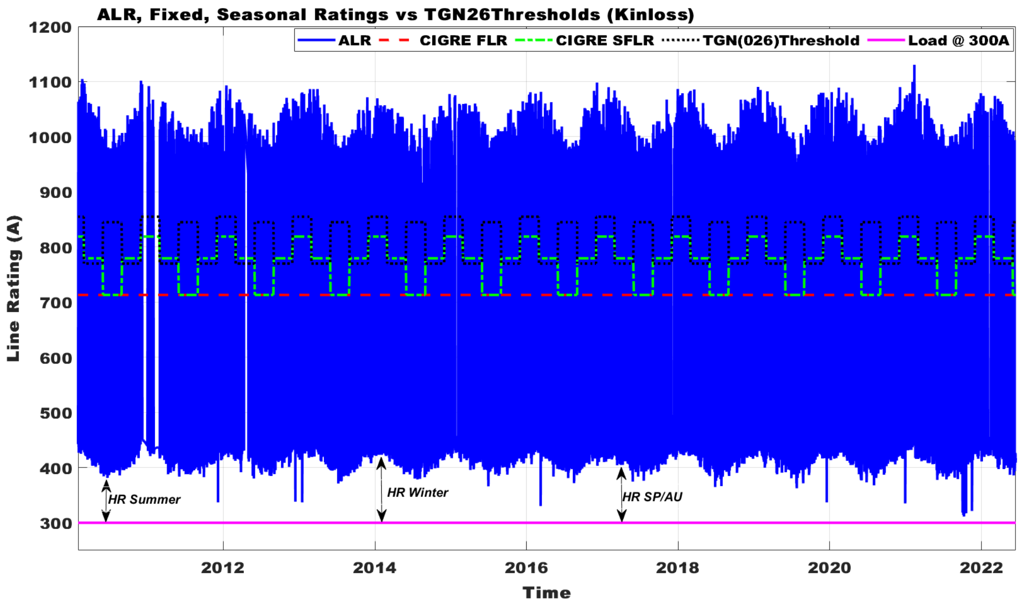

Figure 4.2: Time series Analysis of line rating in Kinloss

is availability to increase loading within this consideration.

4.3 Day and Night Time Evaluation

To evaluate the temporal variation in line capacity due to weather fluctuations during day and night, the line ratings at the both sites were assessed separately for daytime (9 AM – 3 PM) and nighttime (10 PM – 4 AM) hours. The goal is to identify potential capacity advantages under cooler nighttime conditions and validate the suitability of weather-based LR for operational flexibility.

4.3.1 Kinloss Daytime

The allowable line rating (ALR) typically ranges from 600 A to over 1000 A, with a maximum recorded value of 1098 A. During daytime, the minimum rating is 311 A, which is slightly above the load level but still considered acceptable. The ALR consistently exceeds both the fixedline rating (FLR) and seasonal firm line rating (SFLR) most of the time, indicating that daytime weather conditions are generally favorable for higher line ratings, even in the presence of solar radiation. There is sufficient headroom across all seasons, with the actual load remaining consistently well below even the lowest ALR values.

4.3.2 Kinloss Nighttime

The ALR during nighttime shows a higher performance range, with a maximum rating of 1127 A and a minimum of 318 A. The blue region is generally more stable and elevated compared to the daytime plot, confirming improved line capacity during night. Consistent exceedance over

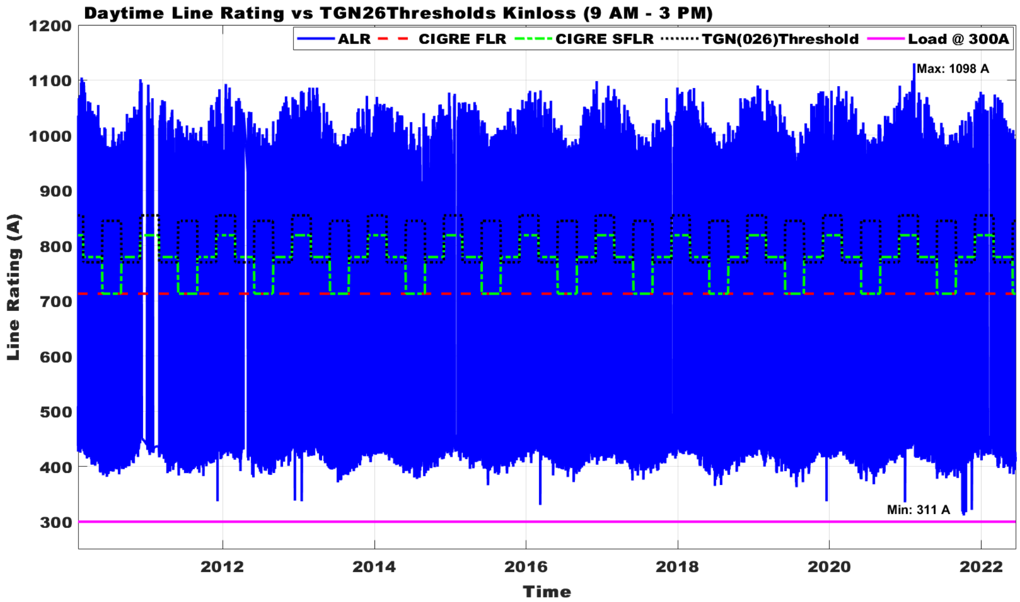

Figure 4.3: Daytime Line Rating in Kinloss

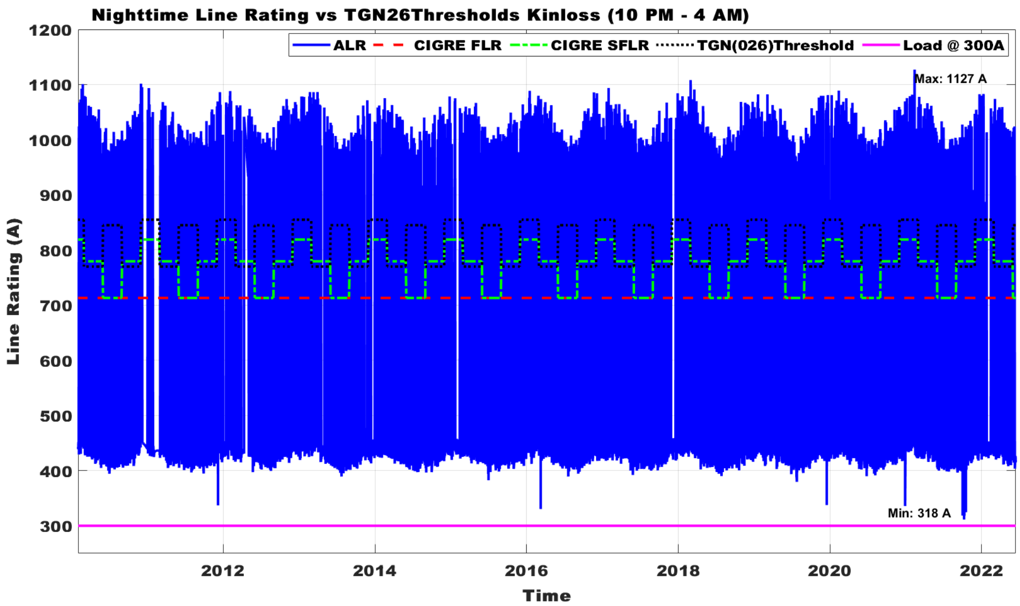

Figure 4.4: Night time Line ratings in Kinloss

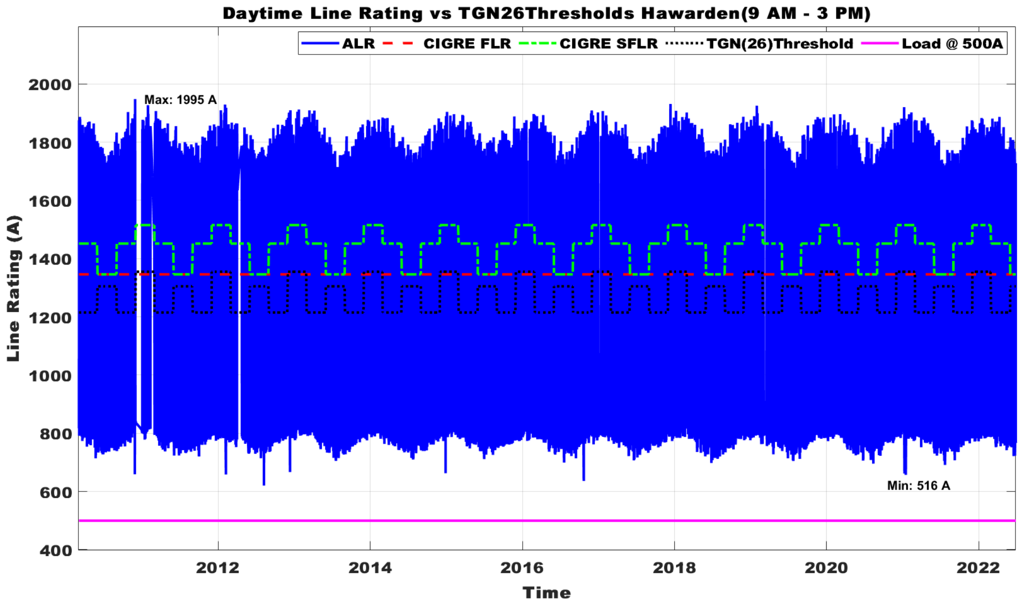

Figure 4.5: Day Time Line rating of Hawarden

static ratings (FLR, SFLR) and regulatory thresholds (TGN(026)) is observed. The 300 A load line lies significantly below the ALR range, providing enhanced headroom during nighttime.

Nighttime ratings are marginally higher and more stable, confirming the benefit of cooler ambient temperatures and the absence of solar heating. Both periods support the feasibility of increasing operational limits or implementing time-of-day-dependent ratings without violating safety margins.

4.3.3 Hawarden Daytime

The ALR consistently exceeds the static ratings, with a maximum rating of 1995 A and a minimum of 516 A, staying well above the load throughout the observed period, as shown in the figure 4.5. Seasonal variation is visible, with higher ratings during cooler months. Despite daytime solar loading, ALR shows minimal reduction due to moderate solar radiation and potentially compensating wind conditions. The TGN threshold remains the upper limit, with no exceedance of thermal safety margins. Headroom of the range of 1-5% is possible to be maintained year-round between load and ALR presuming no increased load due to extent fault scenarios.

4.3.4 Hawarden Nighttime

The ALR shows a slightly improved performance over daytime, peaking at 2009 A, with a minimum of 522 A. This slight uplift is expected, as nighttime conditions reduce ambient temperature and eliminate solar radiation, thus improving convective and radiative cooling as shown in figure 4.6. The margin above the 500 A load remains strong and consistent throughout the time range. ALR remains comfortably above both FLR and SFLR, reinforcing the validity of

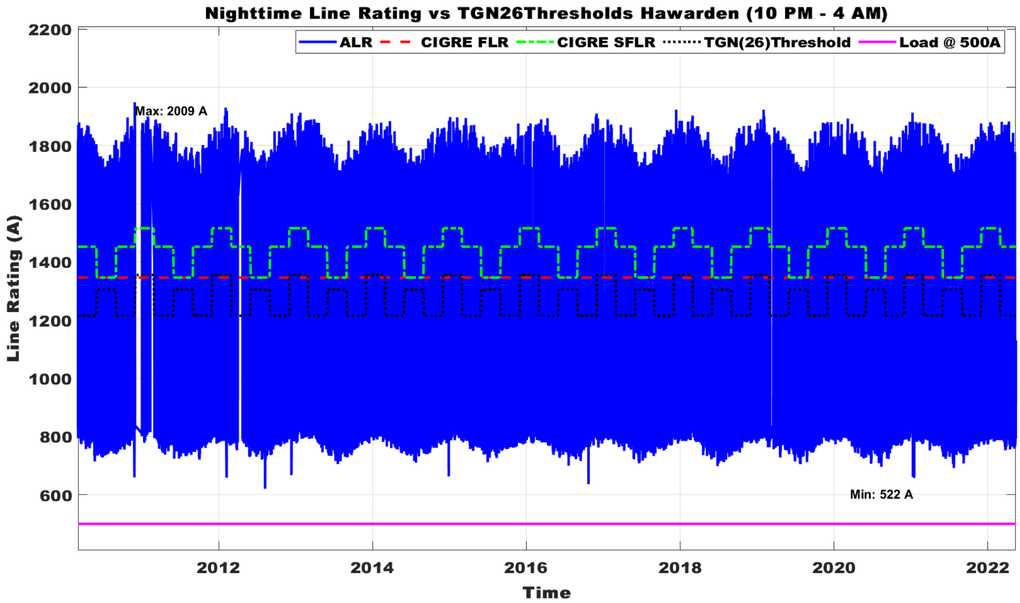

Figure 4.6: Night time Line Ratings in Hawarden

Table 4.1: Summary of Day and Niight of the two sites

Site	Max ALR Day	Max ALR Night	Min ALR Day	Min ALR Night	Day-Night Difference
Kinloss	1098 A	1127 A	311 A	318 A	-3%
Hawarden	1995 A	2009 A	516 A	522 A	-1%

using ALR for operational headroom.

While the difference in ALR between day and night is modest, it aligns with physical expectations of Nighttime ratings, which are marginally higher due to reduced ambient temperatures and the absence of solar radiation. However, the dominant influence of wind speed and the large gap between the ambient and design temperatures (90°C) tend to moderate the sensitivity of ratings to weather variation.

The fixed load of 500 A lies well below the minimum ALR at all times, indicating strong potential operational flexibility and high reliability under both scenarios.

4.4 Other Considerations

Recent publications [5],[9] have indicated thermal conductor time response is critical to evaluating line ratings and static line ratings. The published literature suggests that smaller variations and spreads of line ratings exist which would have implications on defining new dynamic and static line rating exceedance levels. Consequently, the present CIGRE and IEEE analytical methods would need to be adjusted to incorporate effectively this response. In addition, the analytical methods do not take into account factors such as wind direction relative to conductor lines, nor the impact of humidity. Recent work has shown humidity is correlated in some part with line rating evaluation (SSEN report) as well as potentially wind direction. Recommendations for future evaluation include establishing the impact of humidity, conductor time response and wind direction. It is important to determine how these factors may potentially influence any changes not only to the analytical formulations but also whether TGN26 and CIGRE static line ratings should be adjusted in some way to incorporate a more effective inclusion. This could thus increase or validate increased safety load headroom. The frequency at which weather data is captured is a significant issue. It is essential to evaluate the optimal time duration for collecting weather data and understand how this relates to line ratings and the timestamps associated with the weather data.

Further work is needed to quantify how closely regionalised weather measurement data locations should be to associated transmission lines. This ensures the consistent evaluation of appropriate and meaningful line ratings.

5 Conclusion

This report outlines the application of a developed applied line rating methodology that incorporates dynamic, seasonal, and fixed environmental factors. By utilizing weather data with the IEEE 738 and CIGRE rating models, the method provides a representation of conductor thermal capacity for two UK transmission lines: Hawarden (275 kV Twin Rubus AAAC) and Kinloss (132 kV 1x300 mm² Upas AAAC).

The analysis confirms that Analytical Line Ratings (ALR), derived from weather conditions, consistently exceed the conservative Fixed Line Ratings (FLR), Seasonal Fixed Line Ratings (SFLR) and TGN26 levels, particularly in summer periods. In winter and low-temperature seasons, the line rating values increase, indicating a level of potential untapped operational headroom, especially under favorable weather conditions such as high wind speeds and low ambient temperatures.

A key focus of the study was the evaluation of line rating during the day compared to nighttime. Although the difference between daytime and nighttime ratings was modest, it aligned with expected thermal behavior: (i) Nighttime ALR values were consistently slightly higher, primarily due to the absence of solar radiation and lower ambient temperatures. (ii) Hawarden demonstrated a greater absolute line capacity, with ALR often exceeding 1900 A, while Kinloss, although lower in rating due to its conductor and voltage level, maintained a safe operational margin above its 300 A load.

The findings suggest that implementing the developed ALR method and a time-of-day-based scheduling could facilitate at least a potential 1-5% headroom increase in load capacity without sever impact on the line exceeding limits, even for twin lines operating at present current levels.

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