energyline
Electricity Networks Expertise

REVISE – WP.6

WIND FARM CONNECTION STATIC LINE RATINGS

ALPHA PHASE

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EXECUTIVE SUMMARY

In order to meet the Net Zero targets of the UK Government, there is an increasing requirement to integrate renewable energy sources into the existing transmission network. However, it is constrained by the limited amount of energy that can be transferred by the existing overhead line circuits – which leads to significant monetary losses. The current methodology for rating overhead lines in the UK is based on TGN26 which uses historical environmental data captured in the 1980s and is applied uniformly across the UK disregarding local/regional climate variations. Improving the understanding of line ratings with modern toolsets, may offer the potential to revise line ratings without the requirement for physical modifications.

Energyline have been commissioned to demonstrate a supplementary methodology, specifically for wind farm connection ratings as part of the SIF funded project: "Revisiting and Evaluating Environmental Inputs on-Line Ratings" (REVISE) project. This report documents the findings of one part of Work Package 6 of the Alpha phase of the Revise project.

The design process has been described and a method for assessing the drop in wind speed across an OHL route with computational fluid dynamics (namely WindSim) has been demonstrated, in the particular case studied i.e. Muaitheabhal wind farm, construction costs could be reduced from ~£5.32M to ~£2.66M by enabling a smaller standard conductor and a compatible support type.

The method proposed also offers promise for allowing the reassessment of existing windfarm connections where additional capacity is required and therefore negating the need for re-development.

The methodology is only beneficial when conductor selection changes therefore it should be considered only when ratings require marginal adjustment, these 'margins' will require further consideration. This may limit the applicability of the method however, the capital cost savings are likely to outweigh development/ proving costs.

Unlike the broader REVISE scheme, this wind farm-specific approach allows validation through software modelling and targeted field measurements in the near term i.e. does the software accurately model the drop in windspeeds.

Contents

1. INTRODUCTION

In order to meet the Net Zero targets of the UK Government, there is an increasing requirement to integrate renewable energy sources into the existing transmission network. However, it is constrained by the limited amount of energy that can be transferred by the existing overhead line circuits – which leads to significant monetary losses. The current methodology for rating overhead lines in the UK is based on TGN26 which uses historical environmental data captured in the 1980s and is applied uniformly across the UK disregarding local/regional climate variations. Improving the understanding of line ratings with modern toolsets, may offer the potential to revise line ratings without the requirement for physical modifications.

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The relevant characteristics to line ratings for a windfarm connection are presented within the report and have been applied to a planned route connecting Muaitheabhal Wind Farm as a demonstration. The design process is discussed as to how an alternative methodology may practically be applied

1.1. TERMS OF REFERENCE

The terms of reference for Work Package 6 was developed through scoping sessions with SSEN and other collaborators.

The Alpha phase deliverable D6.5 is for a justification paper for a wind farm specific static line rating methodology which is to "demonstrate design procedure/process outline which could be practically adopted for windfarms".

1.2. NEEDS CASE

"Britain will not get a clean power grid by 2030 unless an unprecedented volume of new renewable power and storage is connected to electricity networks" Akshay Kaul, Ofgem's Director General for Infrastructure, (Kaul, 2025).

The transition to renewable energy is central to the UK's net-zero commitments, with wind energy playing a pivotal role. As of March 2024, the UK had over 700 GW of renewable energy projects in the grid connection queue, with wait times exceeding 10-15 years in some cases, (Abbott, 2024). Connection reforms in early 2025 have rationalised these numbers, which were being inflated by placeholders in the queue, but the number of new connections remains at an all-time high. The UK government has committed to double the onshore capacity from 15-30GW by 2030.

One of the primary barriers to windfarm development is the availability and accessibility of grid connections. The UK's transmission and distribution networks are under increasing pressure, with constrained capacity in many regions. As of 2023, 90% of the UK's grid connections are already allocated, and reinforcement requirements add substantial delays, (Ofgem, 2023). Furthermore, uncertainty in connection costs—ranging from £500,000 to £10 million per project—alongside curtailment risks and regulatory compliance, can deter investors, (Ofgem, 2006).

The process of developing and connecting windfarms is complex, often facing significant delays, cost uncertainties, and regulatory challenges. Developers seek to maximise the output of the windfarm area, and this can lead to modification applications to the connection agreement which may lead to abortive design work for the connection and further project delays.

Technology selection (supports and conductors) for new windfarm connections has a substantial effect on the cost of a new connection, and the need for reinforcement/ upgrade or rebuild where existing connections may not have the required capacity to match the generator output can protract connection programmes.

Technological innovations which may ease this burden in the near term would be welcome. The REVISE project is targeted at Static Line Ratings on a grid scale, it is anticipated that the demonstration and proving of this methodology before it can be accepted and be used in the design of new connections may be years away. A targeted approach for certain connection types may offer a more expedited proving and acceptance process.

1.3. OHL RATING SUMMARY

The following section is intended to give the reader a general understanding of the current approach to OHL ratings and to provide context for the subsequent sections regarding wind speed.

Overhead line ratings refer to the current carrying capacity of the circuit without exceeding the temperature limit of the conductor system, this is a critical parameter in the design, operation, and maintenance of transmission and distributions circuits.

In Great Britain the ratings methodology that has been used since the 1980s is defined by National Grid in TGN26 “Circuit Ratings for Overhead Lines”. These are a set of standard ‘static ratings’ which are defined seasonally for pre-fault and post-fault conditions. The ratings are derived using a probabilistic approach to the exceedance of the thermal limit of the conductor and adopt conservative meteorological parameters in the calculation for the steady-state heat balance equation. Three rating seasons are defined: Winter, Spring/Autumn and Summer, which are characterised by different ambient temperatures.

The post-fault rating is the maximum continuous thermal rating that can be used for up to 24 hours after a fault has occurred, they are set to approximately 12% higher than what the line has been profiled for. The pre-fault rating has been set to 84% of the post-fault rating, which essentially eliminates the risk of exceeding the conductor’s rated temperature under normal conditions.

The exact ratings contained within TGN 26 are notoriously difficult to replicate however Cigre Technical Brochure 601 “Guide for Thermal Rating Calculations of Overhead Lines” presents a steady state thermal rating calculation which is understood to be the basis to TGN 26. The conductor ratings is a thermodynamics problem where the conductor is considered to be in a “steady state”

In the steady state, the heat produced by the current, solar radiation, magnetic heating, and corona heating is equal to heat dissipated by convective, radiative and evaporative cooling. Figure 1 presents the conductor heating and cooling. The heat balance can be written as below:

$$PJ + PS + PM + Pi = PC + Pr + Pw$$

Where PJ is the joule heating, PS the solar heating, PM is the magnetic heating, Pi the corona heating, PC is the convective heating, Pr is the radiative heating and Pw is the evaporative heating. Figure 1 below is a graphic of the heating and cooling parameters.

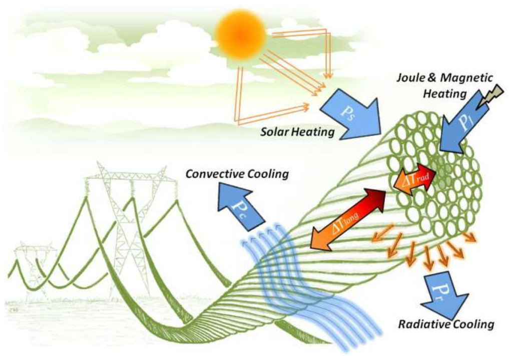

Figure 1 - Heating and cooling of an Overhead Line conductor (Cigre TB601)

Of these cooling parameters, forced convective cooling has the greatest impact upon line rating. The data shown in Figure 2 shows the effect the incremental increase in wind speed has on the conductor rating. The calculations were done at 132kV using single bundle conductors. The conductors chosen for the study were Araucaria, Rubus, totara and Upas. These where chosen as upas and Totara are used mainly for Poles and Araucaria and Rubus predominantly used on towers as they are larger.

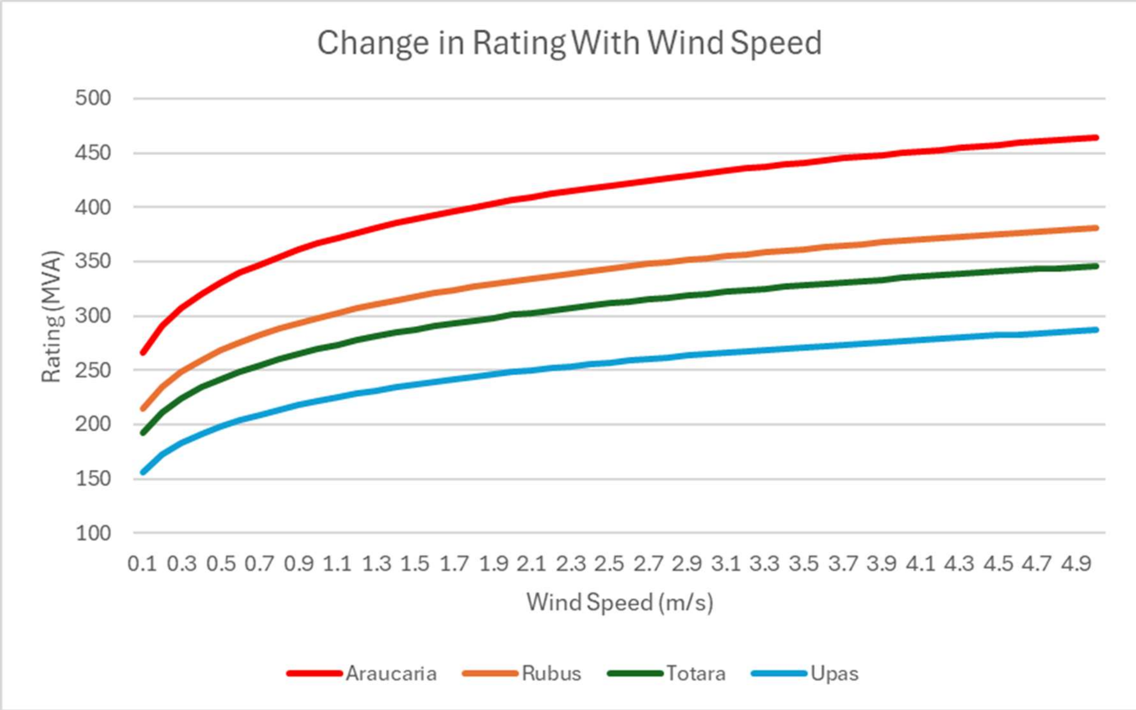

Figure 2 - Wind speed effect on conductor rating (132kV @90°C)

With reference to Figure 2; For a rating requirement of 250MVA and using a wind speed of 0.5m/s, Rubus conductor would be the appropriate conductor system, at 0.7m/s Totara would achieve the required rating and at 2.1 m/s, Upas would achieve the required rating.

2. METHODOLOGY DEVELOPMENT

2.1. OBJECTIVE

The terms of reference set the overall objective for this work package i.e. "demonstrate design procedure/ process outline which could be practically adopted for windfarms".

The methodology is based upon the supposition that the 'Still Air' wind speed of 0.5m/s used for static line ratings calculations may be conservative for windfarms which operate at peak output in windy conditions.

Therefore, the objective is to demonstrate that the assumption of 0.5m/s wind speed used in the ratings heat balance equation calculation can be increased and to demonstrate a means of establishing the confidence with which this can be increased.

2.2. DESIGN PROCESS

The following section describes the design process for OHLs and how a windfarm specific methodology could be incorporated into business as usual.

OHL Design is typically a staged or gated process with multiple design studies undertaken to establish the feasibility of a design and to develop the design for construction. Schemes can be classified as either 'New Build' or 'Reutilisation' and both start with determining the appropriate conductor system for the required rating.

Until the early 2000s and the introduction of the Probabilistic design basis OHLs were designed to a Deterministic design basis. The latter relied heavily upon 'generic' designs and only with the development of sufficient computational power has the probabilistic design basis been adopted. However, the ratings calculations for OHLs have never become 'site specific' largely due to the perceived difficulty in establishing meteorological parameters that differ from the 'tried and tested' (deterministic).

Line rating calculations are performed to establish the appropriate profiling temperature (the sag of the conductors which dictates support heights) as well as confirming the correct conductor size, for ease, engineers have compiled schedules of typical rating values in documents such as National Grid's TGN26. These are all based on the 'default' weather parameters.

An adjustment to the wind speed assumed within this calculation would be trivial. The determination of the appropriate wind speed to use is complex and therefore it would be envisaged that this route specific methodology only be used when all of the following are satisfied:

1
- Connection is a two ended circuit from a windfarm
- No other export sources i.e. batteries are planned at the remote end

2
- Rating is within X% of 'standard' line rating for selected conductor. i.e. a marginal change in rating could influence conductor system selection.

3
- No other plant/ equipment/ underground cable which may limit the rating is present in the circuit - Existing Line Only

2.3. WIND FARM CHARACTERISTICS

As the nature of the generation source is key to the rationalisation of the methodology, relevant characteristics must be determined.

Cut in speed is the minimum wind speed required in order for a turbine to begin generating power output. **Error! Reference source not found.** shows the power output of a turbine against steady wind speeds. The cut-in speed typically around 4m/s is when the blades start rotating and generating power. As wind speeds increase, more electricity is generated until it reaches a limit, known as the rated speed. This is the point that the turbine produces its maximum, or rated power. As the wind speed continues to increase, the power generated by the turbine remains constant until it eventually hits a cut-out speed varies by turbine and shuts down to prevent unnecessary strain or damages, (US Department of energy, 2024).

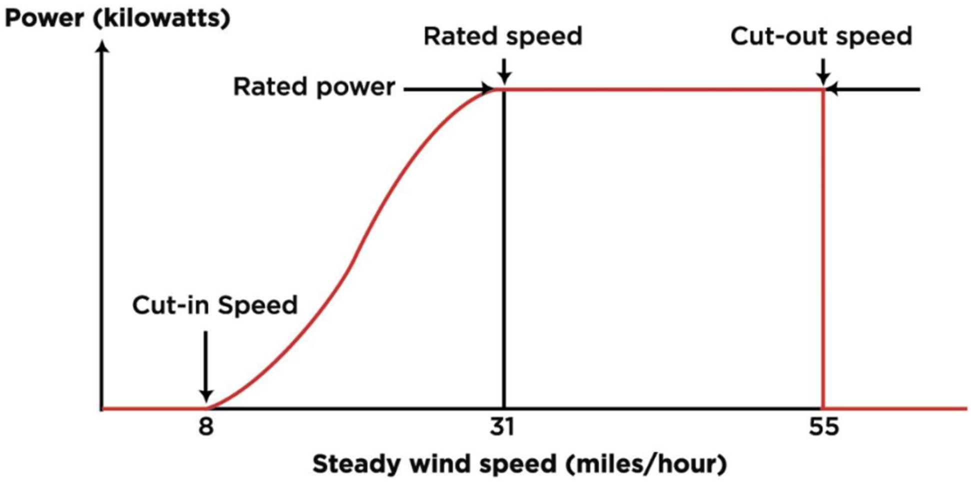

Figure 3 - Typical Wind Turbine Power with Steady Wind Speed, (US Department of energy, 2024)

Wind farms typically have a cut-in speed around 4 m/s with required peak wind speeds being around 10-13 m/s. In reality, the uncertainty of wind speed, direction and turbulence are geographically dependent, and a real-time monitoring system could provide actual atmospheric conditions for ampacity prediction at a given time and place, (Fu, 2010).

Other relevant aspects of the wind farm may include the wake effects of the turbines themselves. Various studies have reported velocity reductions in the wind turbine wake. (G.Smith, 2006) presents an advanced wake model discussing velocity at different distances at 2.5RD the velocity reduction is measured at 60%, followed by 35% at 5RD at which point the transition region begins and 20% at 10RD. This may be relevant where an OHL is in close proximity to the turbines themselves.

2.4. ROUTE CHARACTERISTICS

The following sections describe and explain the route characteristics deemed to be the most important when determining the variability of the wind speed across an OHL route.

2.4.1. Route length

Route length is perhaps the most obvious characteristic of the OHL which may lead to concern over the ability to assess/ predict the wind speed in every location based on observations at another.

It is also, only relevant as a result of the following features of the route, as it is largely the topography and terrain which impacts variability in windspeed at near ground levels.

It may become practical through further examination to define whether very short OHLs can be assumed to be exposed to a consistent wind speed. For the purposes of this report, route length only becomes relevant in so far as the line as a whole is able to be practically assessed.

2.4.2. Altitude

The increase in altitude is shown to impact the wind speeds as shown in Figure 4 and Figure 5. For instance, a measurement of wind speed taken 20 metres above ground level will yield a different result than one taken at 50 meters. This wind variation with altitude is called windshear. It demonstrates that unless the wind is being blocked by a tall obstacle, its speed increases with altitude, (Wind Logger, 2018).

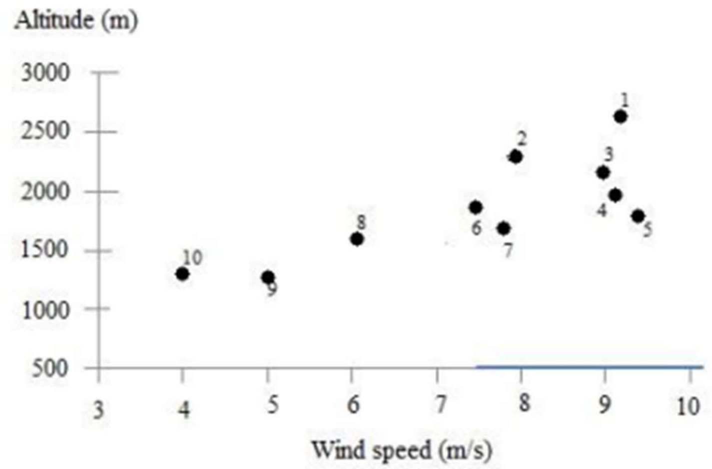

Figure 4- The influence of altitude on the mean wind speed (wind-exposed areas), (Rusu, 2016)

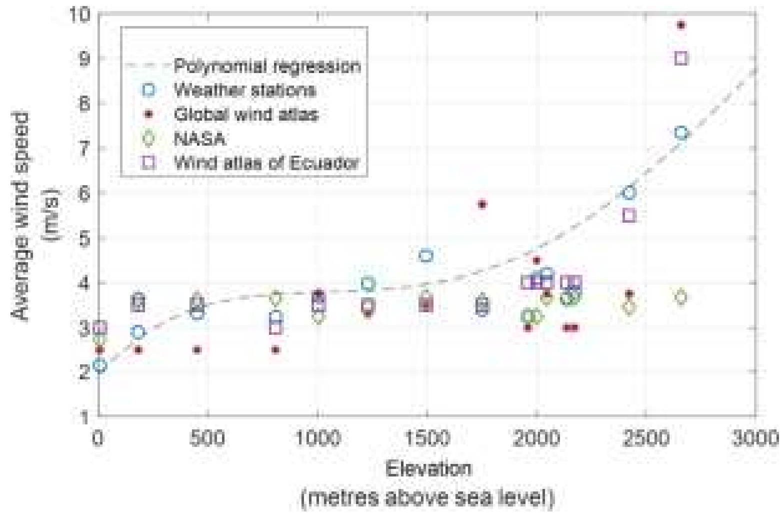

Figure 5- Average wind speed and terrain elevation obtained from weather stations, along with other data sources for the same geographic locations: Global Wind Atlas, NASA, and Wind Atlas of Ecuador, (Solano, 2021)

This is worthing noting as if a line has a severe change in altitude along the designated route, it could lead to a drastic change in wind speeds.

The relevance of the support heights may also be relevant to the prediction of wind speeds.

2.4.3. Wind Angle

Wind angle or "angle of attack" is used during the ratings calculation to calculate a Nusselt number. It has been observed that the Nusselt number increases with the wind angle. The reason for this may be separation of flow once contact is made with the conductor, (Chaudhary, 2016). The Nusselt number is a key parameter in the calculation of convective cooling, the increase in wind angle leads to an increase in the cooling of the conductor. This is due to the wind angle being perpendicular to the line providing better convective cooling and an increase in rating.

The default assumption within the calculations is a 90degree angle of incidence, the wind angle has a significant effect on line rating. this is demonstrated in Figure 6**Error! Reference source not found.** and Figure 7 which show the effect of reducing this angle.

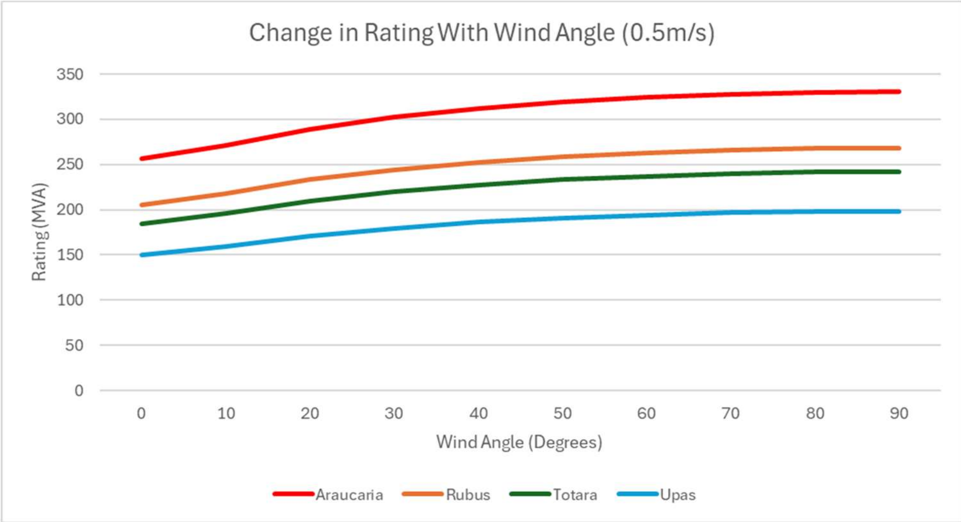

Figure 6 – Change in conductor rating (132kV @90°C) with wind angle at 0.5m/s velocity for AAAC conductors

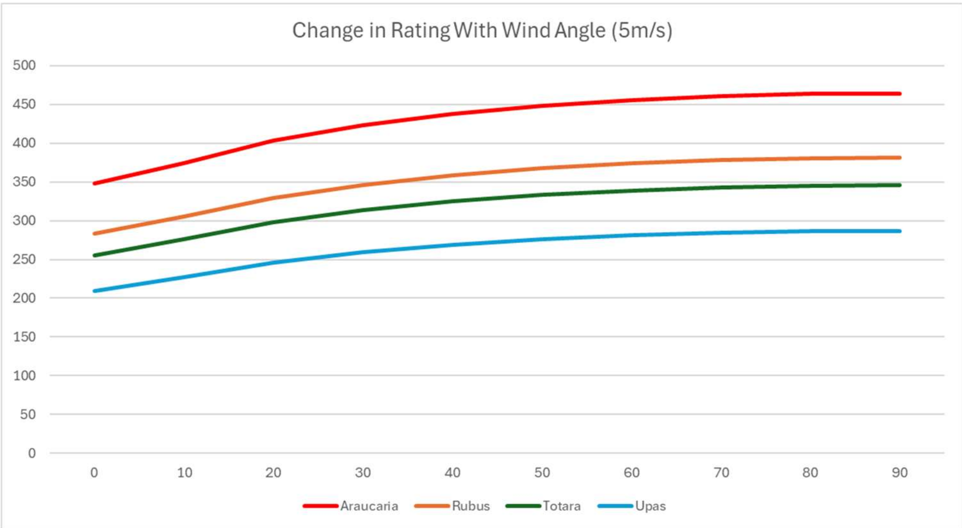

Figure 7- Change in conductor rating (132kV @90°C) with wind angle at 5m/s velocity for AAAC conductors

The assumption that the wind angle is 90° to the line is unusual in the line rating calculation as it is one of the only parameters that has not been considered more onerously.

Most OHLs are not perfectly straight, far from it, and therefore the wind is likely to act in may differing directions across the route length.

2.4.4. Topography

Major topographic features, such as escarpments, hills, and ridges, have strong effects on wind speed as they modify the flow of the wind in the area. These topographic features act as obstructions to the boundary layer accelerating the wind near the ground, which leads to increased wind pressure on buildings located in such regions, (Ngo, 2008). This also means that depending on the site location and topography the effects of sheltering can also take place. Similarly, if the area is particularly built up the effects of blocking or tunnelling can occur depending on the layout of the topography.

The terrain roughness and orography factors can be calculated and applied to the wind speed. Results have shown that the more open and flatter the surrounding area is, the higher the wind speeds will be. As well as the tower location and height along the slop could also have an impact. The greater coverage from trees and buildings has also shown to decrease the wind speed at the location.

Utilising equations from BS EN 1991-1-4, the wind speed can be affected by both the length and the height of the slope. The methodology for these equations covers upwind orography as well as downwind orography for both cliffs and escarpments shown in **Error! Reference source not found.** and hills and ridges.

Terrain roughness can be defined as small vegetation to large, isolated obstacles such as buildings or tree coverage. Although the orography factor has the potential to increase wind speed dependent on slope size and site location, roughness factor tends to decrease wind speed due to coverage leading to a decrease in wind access. The decrease in wind speed from trees and buildings can decrease wind speed by around 50% in a terrain roughness category of 4 even if there are particularly flat hills and escarpments present.

It can be noted that the likelihood for a wind farm connection to be present in a built-up area to be small, as the wind farm would require large open spaces as to not disrupt or reduce the efficiency of turbines. However, there could be a chance of high orography changes as the hills and cliffs could help increase wind speeds at the base of the wind farm.

2.4.5. Sheltering

Surrounding objects such as tree coverage also need to be considered. If no tree lines or other significant obstacles are surrounding the area, then little to no change will occur in wind speeds. However, if obstructions such as trees or buildings surround the designated location it can lead to them potentially altering or blocking the path of the wind and therefore lowering the wind speed. When calculating the effect trees and vegetation have on wind speed the number of trees or blockage of trees is not considered, instead the terrain category can be altered depending on the severity of the coverage.

In most cases, wind turbines are located on high ground in open conditions. Planting trees that will exceed 30 feet in height anywhere in the prevailing wind path is likely to result in reduced wind speeds. Same can be said for overhead lines, (trees-energy-conservation, 2019).

The distance at which an object impacts the wind is also an issue when considering sheltering indicated in Figure 8.

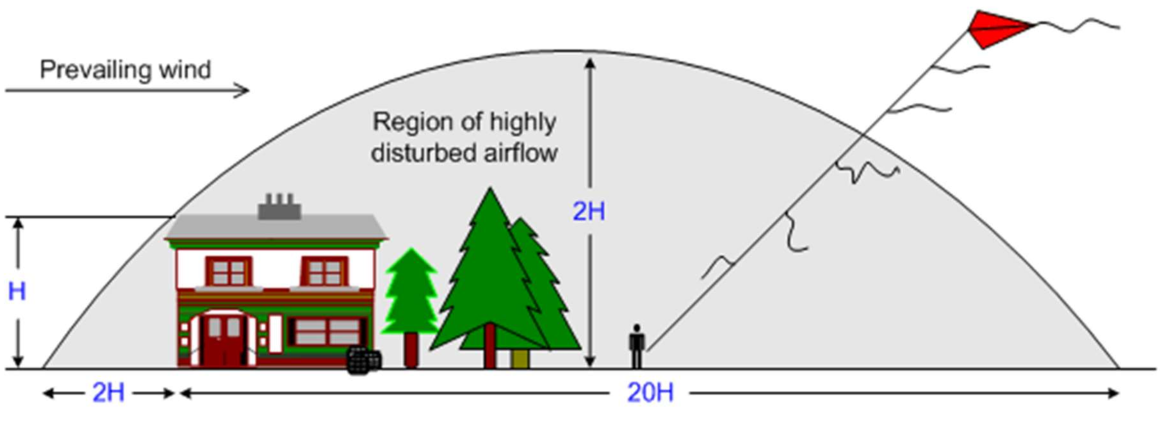

Figure 8- Visual of impacted wind, (Beckers, 2023)

The distance from an obstruction till wind is impacted is dependent on the height of the object. An example of this is a tree line or building. Generally, if a tree or building is our 30 feet high this will impact the wind speeds from up to 600 feet away, (Beckers, 2023).

2.5. COMPUTATIONAL ANALYSIS

The preceding section outlines some of the characteristics of wind farms and ohl routes which may effect wind speeds and demonstrate the difficulty in determining a suitable value that differs from the default.

Windfarm developers have been using computational fluid dynamics to inform the type and placement of turbines for a given site dependent upon the wind characteristics which are greatly influenced by the local topography and obstacles.

A review has been undertaken to identify a suitable software package which could be used to model/ predict the reduction in windspeed across an OHL route.

WindSim is a computational fluid dynamics (CFD) software used for high-resolution wind flow modelling, particularly in complex terrain. It allows users to simulate how wind interacts with natural and man-made obstacles, such as hills, valleys, forests, and buildings, which can significantly impact wind speed. When assessing wind speed drop across an overhead line route, WindSim can model the effects of terrain elevation, surface roughness, and vegetation density on airflow. By incorporating detailed topographical and land-use data, the software predicts areas of turbulence, wind shading, and speed reduction caused by obstacles like dense tree cover or steep slopes.

WindSim is currently used by SSE Renewables, which was a factor in selecting this particular software package as it may be readily available for further demonstration. More importantly, they also have experience of applying the technology to OHL applications, particularly for use in short term forecasting for dynamic line rating applications, the software has been used to identify ‘critical spans’ where sheltering or wind directions may be unfavourable, (Abboud, 2018).

3. METHODOLOGY DEMONSTRATION

3.1. ROUTE SELECTION

A windfarm connection route which is currently under development has been selected to demonstrate a methodology for determining the wind speed to be adopted in the calculation of the OHL rating.

The route meets the criteria set out in **Error! Reference source not found.**:

- The route is two ended and only connects the Muaitheabhal windfarm. No battery storage or other source of generation is planned at the remote end.
- The required rating is 199MVA and therefore the conductor selection is 1x425mm^2 AAAC (Totara) conductor, the support selection is hence driven to be EaSTS (Steel Trident). The summer pre-fault rating of Upas would be ~191MVA and therefore the required rating is only 104% of the next conductor size down than that which has been selected.
- As this is not an existing line, cable interfaces and substation equipment will be rated accordingly and require no further consideration.

The Muaitheabhal wind farm alignment is shown in Figure 9. The alignment runs from Balallan switching station to Muaitheabhal Windfarm Substation.

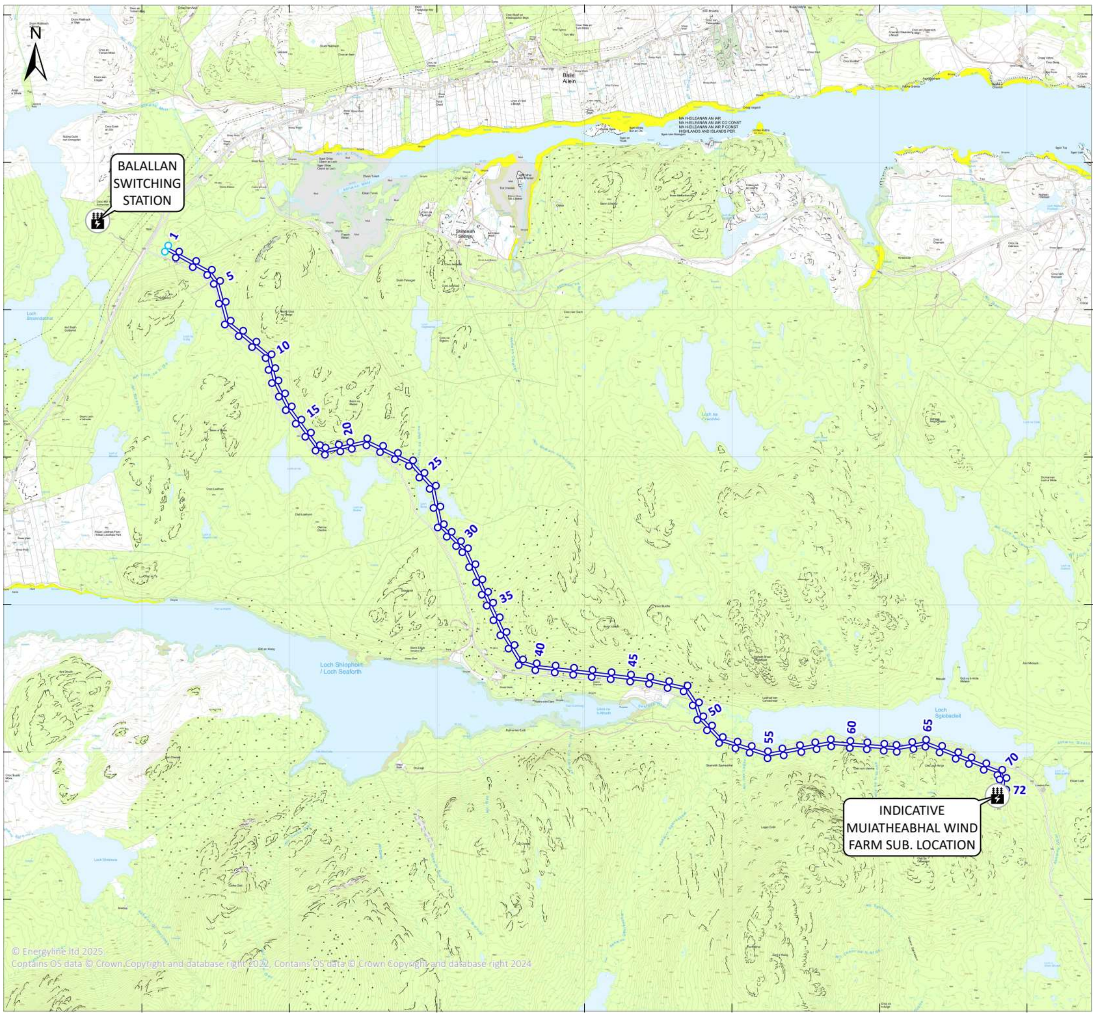

Figure 9- Muaitheabhal Wind Farm Preferred Alignment

Energyline are undertaking the alignment design for this windfarm and therefore had knowledge of the routes characteristics which have biased its selection for demonstration.

3.2. WIND FARM CHARACTERISTICS

Muaitheabhal windfarm consists of 33 turbines with two 6 turbine extensions in the east and the south, each with a peak power wind speed of 13m/s.

Figure 10 shows the proposed turbine layout for the Muaithebhal wind farm. The site consists of three sections A, B and C. With A being the original proposed wind farm and B and C being the proposed extensions. The red outlines the site boundary and the light green outlines the three sections of the windfarm.

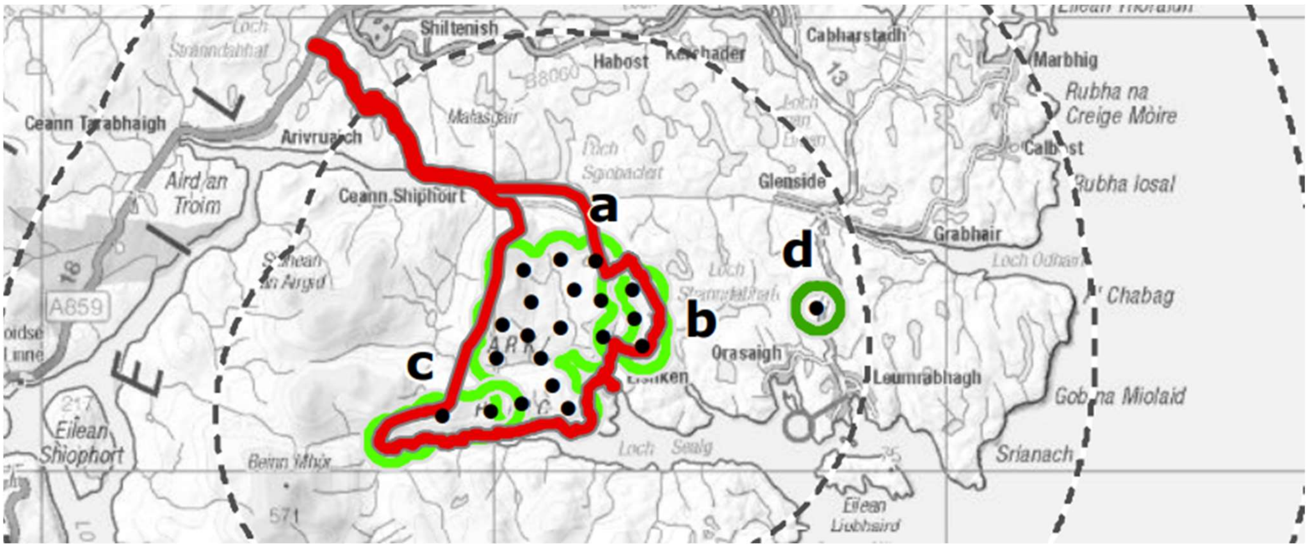

Figure 10- Muaithebhal wind farm turbine layout, (Lewis Wind Power, 2018)

The route Is not expected to be within the three times rotor diameter of the turbines, however, further assessment of the sheltering provided by the turbines may be relevant.

3.3. ROUTE CHARACTERISTICS

The following sections describe the characteristics of the Muaitheabhal route. At present these are purely factual assessments which would be intended to form a 'decision gate' type process i.e. was any one characteristic deemed to be too complex or variable then the default wind speed must be used for the rating calculation.

3.3.1. Route Length

The connection is approximately 8.5km in length running from Muaitheabhal Wind Farm Substation and Balallan Switching station.

3.3.2. Altitude Profile

The altitude of the Muaitheabhal route ranges from ~75m to ~5m altitude as shown in Figure 11.

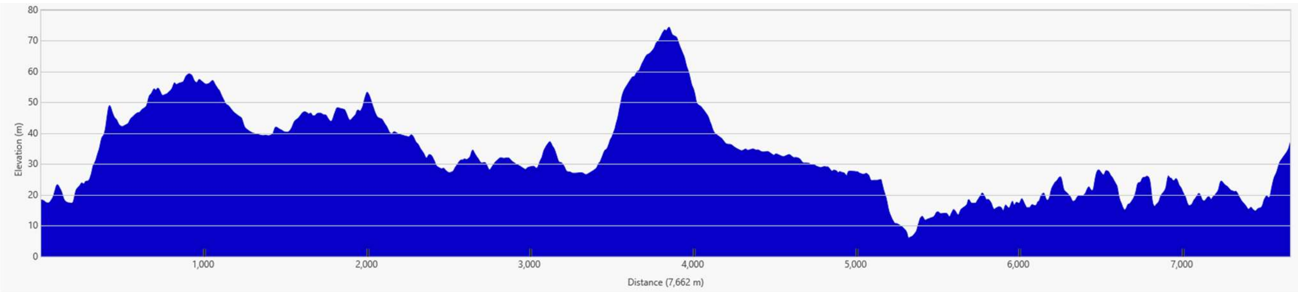

Figure 11- Muaitheabhal Wind Farm Altitude Profile

3.3.3. Wind Angle

The route runs approximately South East to North West, there are multiple points of deviation, no attempt has been made to quantify the deviation into a Total Alignment Deviation value as this would seem difficult to usefully bound/ categorise.

What can usefully be established is that the prevailing south south-westerly wind, see Figure 12, on Harris is approximately perpendicular to the total route length.

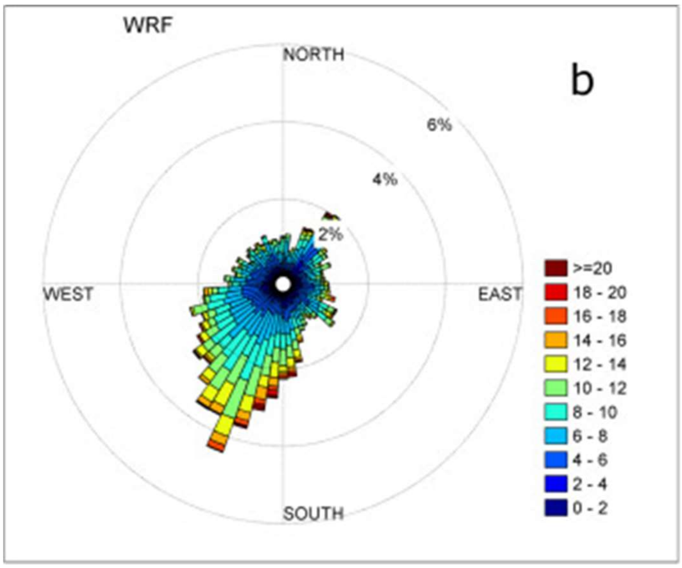

Figure 12- Stornoway airport wind rose (Aleynik, et al., 2016)

3.3.4. Topography

For structural design purposes the route has been classified as terrain category 1. Terrain category 1 is defined in BS EN 1991-4-1 as any terrain containing lakes or flat and horizontal area with negligible vegetation and without obstacles.

3.3.5. Sheltering

No tree lines or other significant obstacles have been identified within 300m of the overhead line.

3.4. WIND SPEED COMPUTATION

WindSim is a computational fluid dynamics (CFD) software that calculates wind speeds in given locations. It considers surrounding geographical terrain and sector angle to show the impact of topography on the wind speeds.

Results from WindSim computation presented in the following show the change in wind speeds along the Muaithebhal route. The initial wind speed was set to 13m/s as this would demonstrate the minimum required wind speeds for peak power output from the wind farm (worst case) as wind speeds could be higher. Each wind speed is taken from a height 13m above ground as this would be the average height of the poles along the line.

The wind speeds are calculated using different sector angles in order to demonstrate the impact of the variable topography. The sector angle represents the angle at which the wind is approaching from, this is defined differently to the wind angle discussed when calculating rating, as this is wind direction and not angle at which the wind hits the conductor. The sector angles were increased incrementally by 30°, with the initial 0° angle representing North. The results show the wind sectors of the compass points along with the sectors that would represent the prevailing south southwest wind shown in Figure 12.

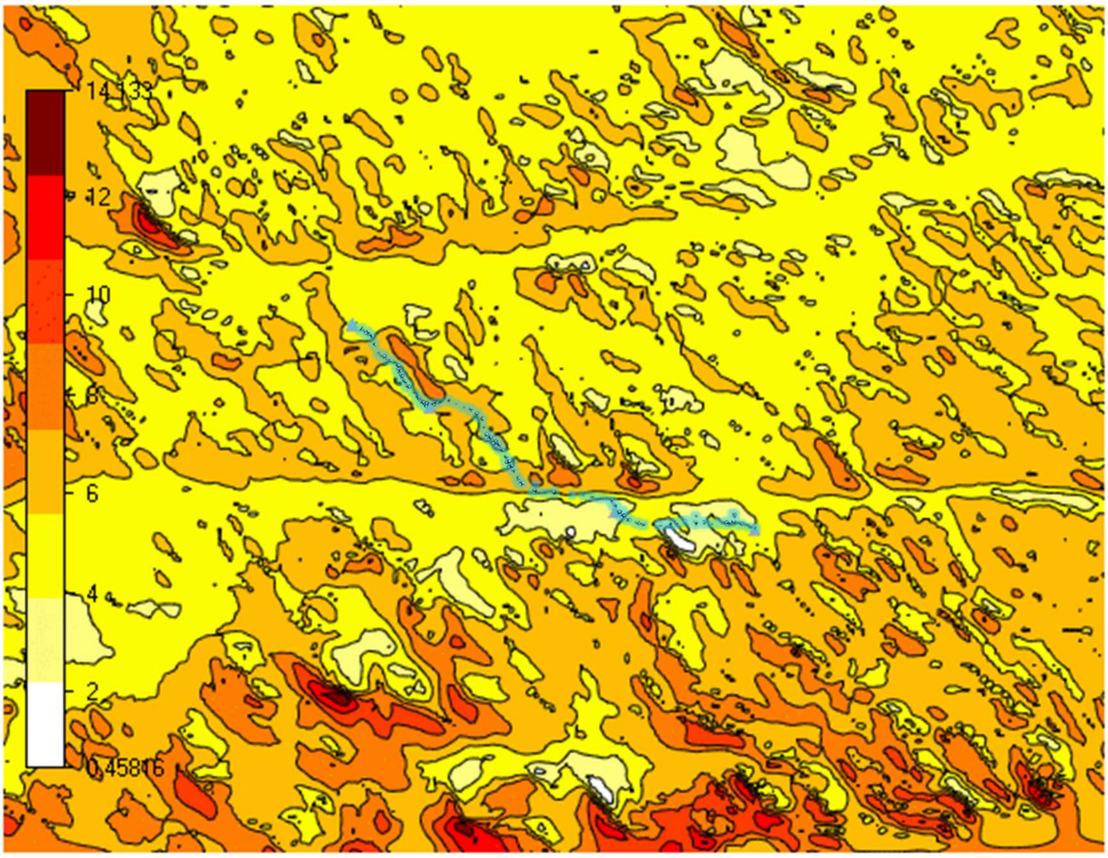

Figure 13- WindSim Wind Speed Graph with Muaitheabhal route overlay, 210° Sector Angle (Prevailing wind angle)

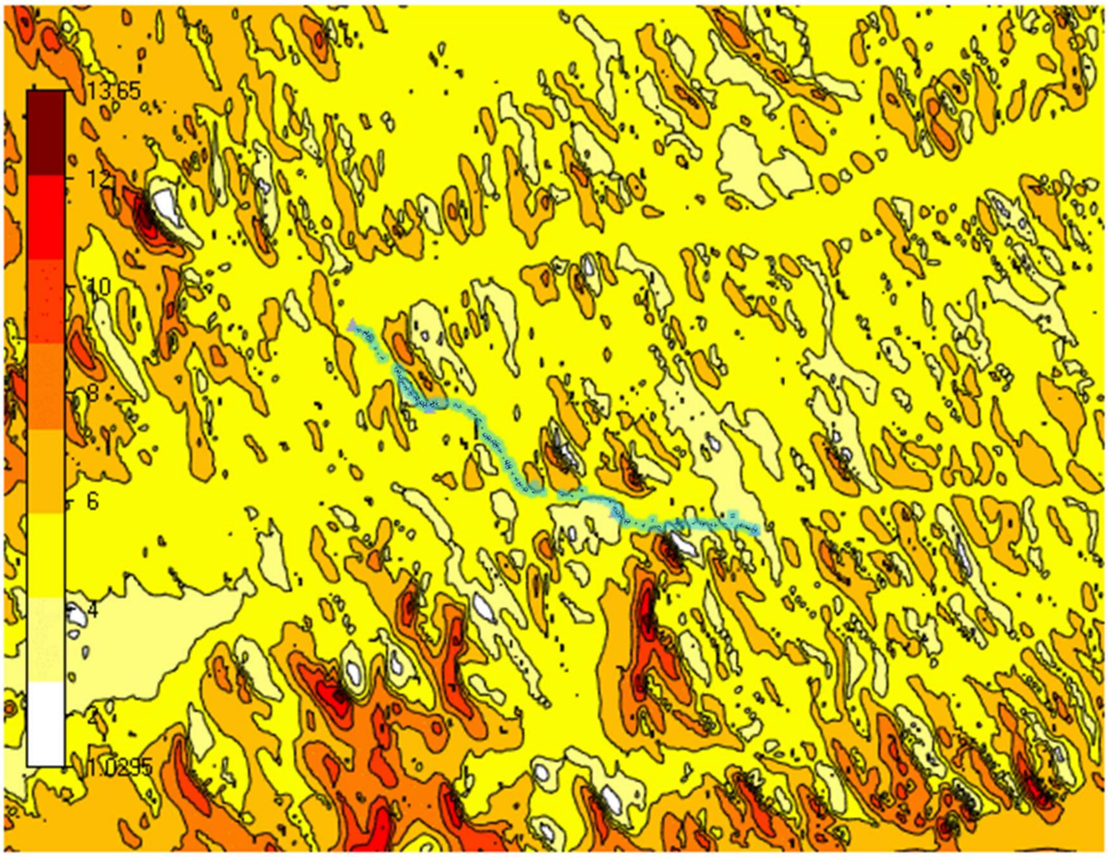

Figure 14- WindSim Wind Speed Graph with Muaitheabhal route overlay, 240° Sector Angle (Prevailing wind angle)

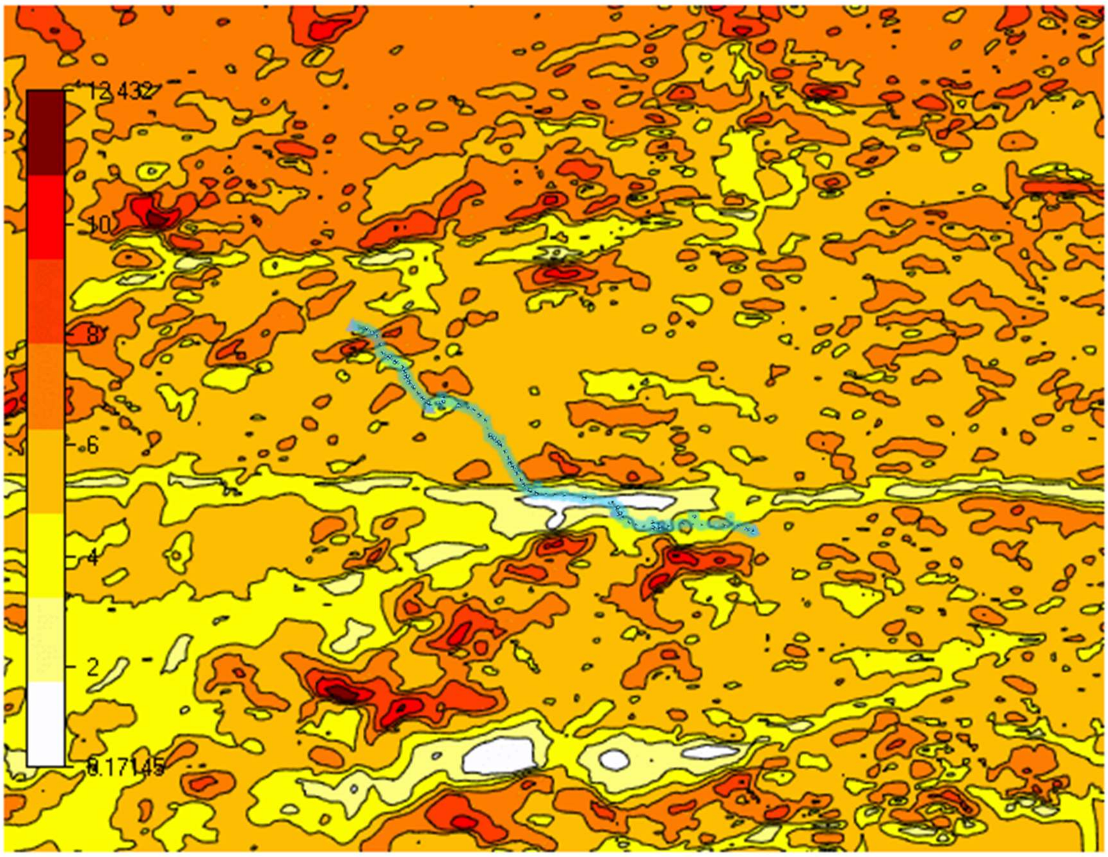

Figure 15- WindSim Wind Speed Graph with Muaitheabhal route overlay, 0° Sector Angle (north)

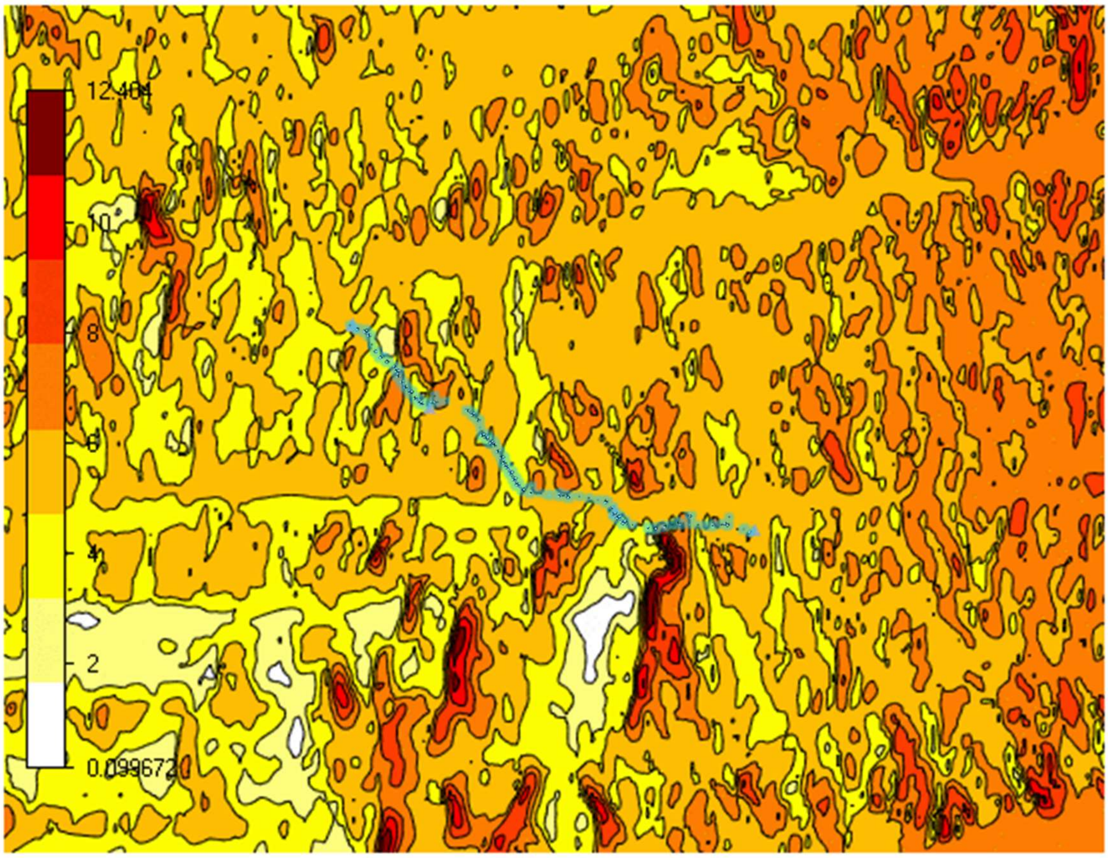

Figure 16- WindSim Wind Speed Graph with Muaitheabhal route overlay, 90° Sector Angle (East)

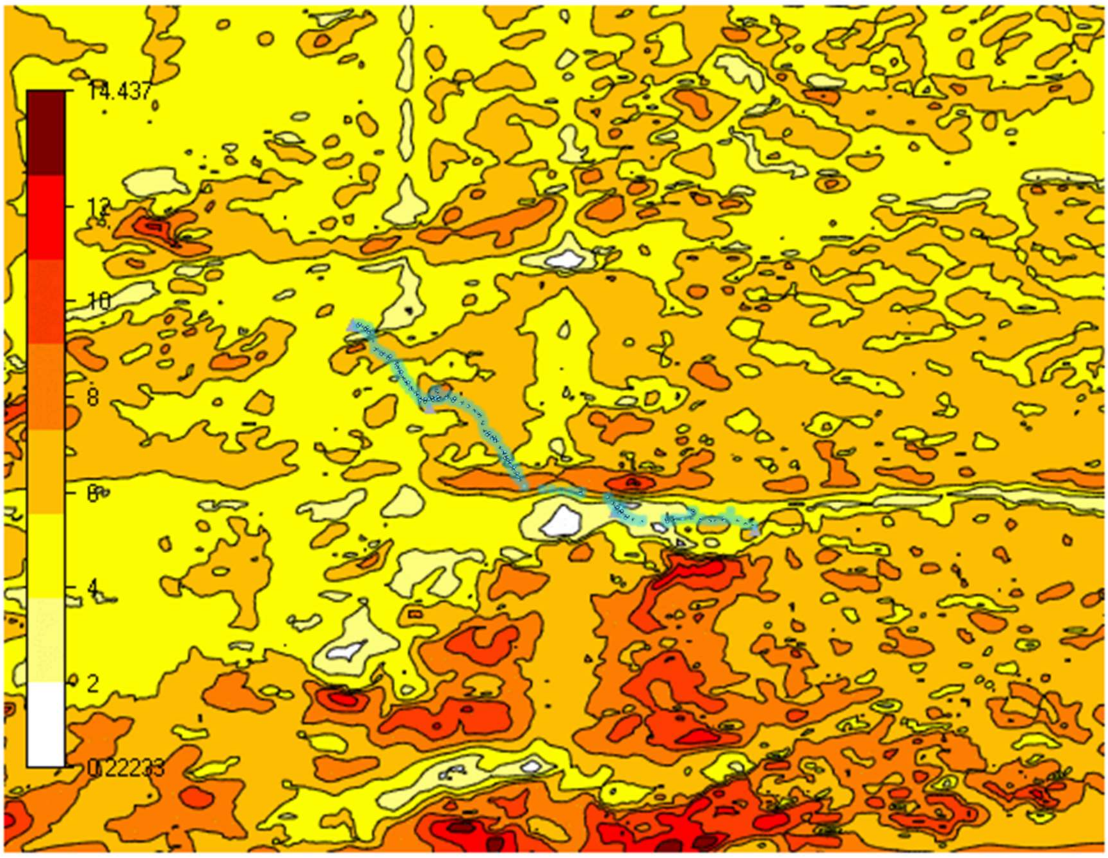

Figure 17- WindSim Wind Speed Graph with Muaitheabhal route overlay, 180° Sector Angle (South)

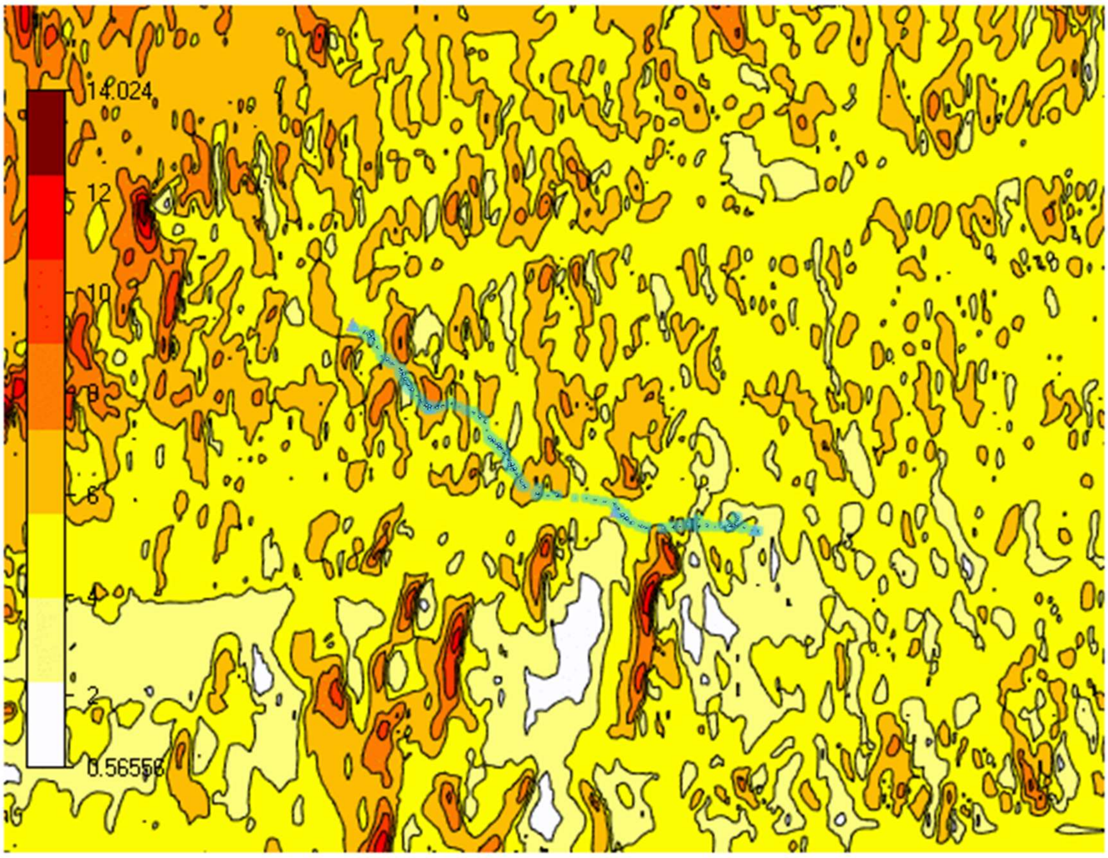

Figure 18- WindSim Wind Speed Graph with Muaitheabhal route overlay, 270° Sector Angle (West)

The results show the changes in windspeed along the route. The north (0°) wind sector results showed a section of line running through areas with wind speeds less than 2m/s. These sections can be seen in Figure 15. The area with reduced wind speeds is indicated by the white areas along the terrain, showing any wind speed less than 2m/s.Further refinement of the model may be possible to assess this area.

3.5. RATING CALCULATION

With the goal of the study being to shift the technology selection to the next standard conductor size down, the wind speed adjustment required to achieve this can be back calculated.

The windspeed required to provide sufficient cooling of Upas to limit its maximum operating temperature to 90°C with a current rating of 199MVA is 0.64m/s. This windspeed would be a 20-fold decrease from the windspeed required for peak power generation. The assessment of the route characteristics and wind speed drop across the route from WindSim would indicate that this value could be confidently increased to this level.

Furthermore, taking the WindSim windspeeds as read (Any factors of safety/ assumptions within the software need to be understood), a minimum windspeed of 2m/s could be used in the ratings calculation. This would provide a current rating increase of 25% to 248MVA for a Upas conductor operating at 90°C.

4. DISCUSSION

The design process/ justification for an increased wind speed has been 'sketched out' for the Muaitheabhal windfarm connection. By enabling the use of the next standard conductor size down this results in a reduction of the benchmark construction cost from ~£5.32M to ~£2.66M for the connection, primarily by virtue of the change in support type which has been identified as being compatible with the conductor system. This is a rudimentary cost comparison and in reality, other means of cost saving could alternatively be considered.

Whilst not presented above, it is conceivable that similar orders of magnitudes of savings are also possible where the need for a new connection is done away with altogether. This could be the case where a windfarm is to be extended, or a new windfarm is constructed adjacent to another. Such a use case may require further consideration due to the large footprint of windfarms, the windspeeds may vary to a greater extent across the site.

The methodology proposed is only advantageous where a change in conductor selection or need for a new connection is negated, this will evidently not be the case for all windfarm connections. Further evidence may need to be sought to quantify the windfarms in the connections queue which could exploit this methodology to justify it's development. However, given the apparent technology readiness level of such a scheme the connection cost savings are likely to dwarf the cost in development and adoption of the methodology.

A part of the needs case for a windfarm specific approach to OHL ratings was the expedience that validation could be undertaken. Unlike the wider REVISE scheme, which may require long term field measurement to justify changes in meteorological parameters, the validation of WindSim (Or other proprietary software) can be achieved in a shorter timescale due to the relationship of the windspeed at remote locations as opposed to the absolute value. It is conceivable that the most topographically complex windfarm connection could be selected and modelled, and the wind speed reduction across the route validated through field measurements in relatively short timeframes.

The methodology being proposed does not conflict with the wider REVISE methodology, if any changes to wind speed are justified through that methodology it is not likely to prevent the use of a greater windspeed where sufficient engineering justification has been established to do so. Changes to values of exceedance or other meteorological parameters are not expected to conflict, however, this requires further understanding and development of the REVISE method.

As has been demonstrated in 3.5 there may be a significant difference between the windspeeds which result in the desired outcome (i.e. marginal increases in the windspeed assumption) and the possible ratings increases which could be justified (i.e. significant increases). In these significant cases, Network Operators may need to decide whether setting standardised boundaries/ limits is appropriate or whether a route specific risk assessment is to be undertaken, this should form a part of the overall development of the methodology.

Utilising software to generate wind speed variations along the proposed route, results showed that all of the route is above a 2m/s windspeed in the prevailing wind direction. There is shown to be a section of the line with a decrease in wind speed with a northerly wind, this could be due to the hills and escarpments causing sheltering or blocking from that angle. Further refinement of the model may be appropriate in this case to establish a more precise predicted windspeed. However, adding wind direction into the equations for line rating exceedance would conceivably where previously no account for this effect has been used would plausibly be an acceptable level of 'risk'.

There is a programme and cost associated with introducing a new study to the OHL design development process. It is envisaged that Network Operators would need to identify/ approve the use of this method on a case by case basis and document this within their specifications. However, setting a precedence/ standard to follow for justification of the values adopted within the ratings calculation as opposed to adopting default values appears to offer substantial savings and possibly will result in the expedition of the connection of new wind farm developments.

It is important to recognise that TGN26 states "The approach accepts that, because of the random variations in wind speed, direction, ambient temperature and solar radiation, the actual temperature of the line may exceed the temperature for which it was profiled." Furthermore, that the wording in the The Electricity Safety, Quality and Continuity Regulations 2002 Part V Clause 17(1) states in relation to conductor heights above ground "the height above ground of any overhead line, at the maximum **likely** temperature of that line" affords some engineering judgement as to the likelihood of achieving the maximum operating temperature.

5. CONCLUSION

A method for assessing the drop in wind speed across an OHL route with computational fluid dynamics has been demonstrated, in the particular case studied i.e. Muaitheabhal wind farm, construction costs could be reduced from ~£5.32M to ~£2.66M by enabling a smaller standard conductor and a compatible support type.

The method proposed also offers promise for allowing the reassessment of existing windfarm connections where additional capacity is required and therefore negating the need for re-development.

The methodology is only beneficial when conductor selection changes therefore it should be considered only when ratings require marginal adjustment, these 'margins' will require further consideration. This may limit the applicability of the method however, the capital cost savings are likely to outweigh development/ proving costs.

Unlike the broader REVISE scheme, this wind farm-specific approach allows validation through software modelling and targeted field measurements in the near term i.e. does the software accurately model the drop in windspeeds.

6. REFERENCES

Document Reference	Document Title	Issue	Date
BS EN 50341-1	Overhead electrical lines exceeding AC 45 kV	N/A	2012
BS EN 50341-2-9	National Normative Aspects (NNA) for Great Britain and Northern Ireland	N/A	2017
TGN(E) 026	Circuit Ratings for Overhead Lines	5	2016
BS EN 1991-1-4	Actions on structures – General actions – Wind actions	N/A	2005
Cigre 601	GUIDE FOR THERMAL RATING CALCULATIONS OF OVERHEAD LINES	N/A	2014

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