A RISK-ASSESSED APPROACH TO OVERHEAD LINE CORRIDOR CLEARANCE MANAGEMENT

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ABSTRACT

Ensuring public safety and the continuity of supply of electricity to customers are essential aspects of overhead line (OHL) asset management. Maintaining the required electrical clearance limits of conductors from the ground, vegetation, roads and other infrastructure within the line corridor is a vital part of this process. Such is the importance of adequately assessing clearances from terrain, obstacles and vegetation that may pose safety risks to members of the public and threaten network reliability, an approach was developed to allow the prioritisation of the most urgent clearance infringements in each of these categories. This approach risk-assesses the magnitude, extent and consequence of clearance infringements and categorises them accordingly.

Practical challenges associated with the basis for vegetation clearance requirements from OHLs were also identified during this process. Vegetation clearance requirements were reviewed and priority-based clearance zones were defined based on conservative assessments of vegetation growth gathered over consecutive years. A case study considering a heavily loaded 110 kV OHL in Ireland demonstrated how the revised approach was successfully utilised to identify clearance issues over terrain, obstacles and vegetation along an OHL corridor.

INTRODUCTION

Electrical clearance limits along OHLs are an important safety concern for distribution system operators. Prudent management along network corridors is essential to eliminate clearance infringements from the ground, buildings, roads, vegetation and other infrastructure that pose safety risks to members of the public and may interrupt the supply of electricity to customers. A notable example is the investigation into the 2003 power outage in Ontario, Canada and some North-Eastern U.S. states which concluded that a major cause of the blackout was trees making contact with OHLs [1]. This occurred despite tree clearances being checked on three of the four lines associated with the fault less than three months prior to the event.

Another pertinent reason to manage clearance requirements is due to the reduced wind cooling effects along OHL corridors sheltered by vegetation which may contribute to excess sags with heightened risk of obstacle contact [2]. Wind speeds can be up to 60 per cent less along these sheltered corridors than in other, more open locations and the direction of the wind may be parallel to that of the line resulting in further reduced cooling effects [3]. Furthermore, differences of up to 50 °C in conductor temperature have been reported along sheltered OHL spans under very high current densities [4]. A notable example of the effects of low wind speeds occurred in the South-East of Ireland where a conductor failed in a densely wooded corridor. An investigation into the fault concluded that low wind speeds within the sheltered region where failure occurred led to temperature excursions beyond nominal limits causing sag exceedance and strength reduction. This is of particular concern on OHLs that are operating close to or at capacity [5].

Considering these previous experiences, the need to develop an approach for risk-assessing and managing clearance infringements is apparent. Therefore, a new approach was applied to a recent project in Ireland involving a heavily loaded 110 kV OHL. This provided a risk-assessed method for prioritising and eliminating potential and/or actual clearance infringements along the OHL using a combination of the following approaches:-

- Technology Requirements:
  - Geospatial Modelling using Lidar Data;
  - Application for Thermal Rating Data Management.
- Clearance Requirements:
  - Risk Classifications for Terrain and Obstacles;
  - Vegetation Grow-in and Falling Tree Risks.

TECHNOLOGY REQUIREMENTS

Ireland's distribution system consists of over 150,000 km of OHLs. Controlling, processing and managing line data for this network in order to optimise future asset management decisions can be challenging. Technologies such as lidar, design software and purpose built in-house applications are important for providing efficient designs and making effective asset management decisions.

Geospatial Modelling

Lidar surveys are used by utility companies for rapidly collecting geospatial information and constructing accurate 3D models of existing OHL assets. These models can be used in conjunction with meteorological and line-load data collected at the time of the survey to perform thermal rating calculations and provide an accurate estimate of conductor temperature and sag. The vast amount of data that can be extracted from lidar flights must be managed and processed effectively in order to optimise its use for asset management decisions.

Lidar information can be particularly useful for identifying locations where any infringements of required clearances are present on the line (as distinct from conductor related issues such as sag exceedance or under-tensioning). This may be used for assessing remedial works to ensure that clearances are achieved and also to report any infringements. While the data collected as part of a lidar survey is very beneficial, it also poses many challenges with regards to the handling, organising and storing of large datasets which contain point cloud data in addition to other line-load and meteorological information.

Thermal Rating Data Manager (TRDM)

Knowledge of OHL conductor temperatures is important for making risk-assessed asset management decisions. The OHL design software employed allows conductor temperature to be calculated based on the line-load and meteorological data collected from lidar surveys; however this information cannot be easily extracted from the large datasets provided by the lidar contractors for easy input into the design software.

To overcome this challenge, an application called the Thermal Rating Data Manager (TRDM) was developed in-house. The TRDM is an application which takes a formatted spreadsheet containing line-load and meteorological data as well as the imported line, span and phase information from the design software as inputs. The TRDM also extracts the relevant span specific information required to complete the thermal rating calculation through the design software's thermal rating function, as shown in Figure 1. Another innovative feature of this application is that it applies corrections as necessary to the date, time, temperature, wind speed (including height adjustments), wind direction, global solar radiation and line-load information efficiently and accurately.

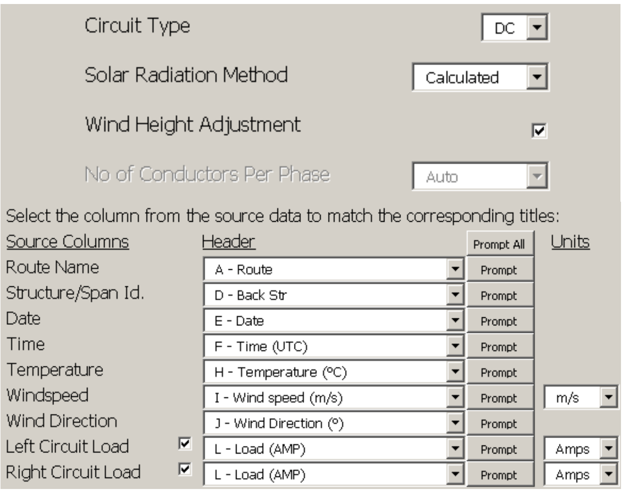


Figure 1: TRDM Information Inputs Interface

The contemporaneous processing of the line-specific information obtained from the lidar survey, in conjunction with line-load and meteorological data, via the TRDM application, facilitates the design software calculating the temperature of the OHL during the survey. Considering normal wind speeds (greater than 1 m/s) and line-load conditions, the estimation of conductor temperature is typically accurate to +/- 5 °C [6]. This is advantageous as it allows the rapid production of accurate clearance reports which inform risk-assessed asset management decisions.

CLEARANCE REQUIREMENTS

The challenge of adequately assessing clearances from terrain, obstacles and vegetation is such that a suitable approach was required to allow prioritisation of the most urgent conflicts in each of these categories. The combined use of lidar and design software allows potential and/or actual clearance infringements to be readily identified and reported to asset management teams so that necessary remedial works can take place.

Terrain and Obstacles

Clearance requirements from OHLs to ground and other obstacles such as roads, railways, rivers and low, medium and high voltage crossings are specified based on three weather cases. The weather conditions considered when specifying clearances from obstacles and terrain in Ireland are the high temperature (typically 80 °C) condition, and the moderate and heavy ice load conditions with a safety factor of 1.25.

Regarding terrain and obstacles, lidar surveys of existing lines frequently identify varying numbers of potential and/or actual clearance infringements. This process is considerably enhanced when clearance infringements are analysed using the design software's thermal rating calculator to determine the conductor temperature at the time of the lidar survey. This is undertaken after the raw data has been processed and organised by the TRDM application. A risk-assessed approach was developed, which, combined with corridor screening, categorises the magnitude, extent and consequence of these infringements. These consider controlling high conductor temperature and ice-only weather conditions. The infringements can be classified in accordance with Table 1 as Low, Medium, High or Extreme risk.

Table 1: Terrain and Obstacle Risk Classifications (All Voltages)

Risk Classification	Clearance Infringement from Farmland / Bog	Clearance Infringement from Other Obstacles (Roads, Rail, etc.)
Low	Less than 0.25 m	N/A
Medium	Between 0.25 m and 0.75 m	Less than 0.25 m
High	Between 0.75 m and 2 m	Between 0.25 m and 0.75 m
Extreme	Greater than 2 m	Greater than 0.75 m

Vegetation

The approach for specifying vegetation clearance requirements in Ireland is based on four weather conditions outlined in EN50341-3-11 [7]. This document specifies the clearance requirements between trees and OHLs under maximum operating temperature, high wind, ice-only and combined wind and ice conditions. An empirical rule for tree clearances was introduced in Ireland in the 1970s which allowed timber cutting inspectors to implement these clearance requirements. Certain practical challenges identified with this rule included difficulty in applying clearances specified from the maximum operating temperature to the OHL normally operating at lower load levels and temperatures.

This issue was overcome by an innovative approach which specified clearance requirements based on the assumption of conductor sag at a conservative 0 °C temperature for a range of typical spans. A site clearance margin, as illustrated in Figure 2, was calculated as a function of the 0 °C to 80 °C sag range and the clearance requirements for trees under OHLs. The site clearance margin varies depending on the line voltage, span length and line configuration. In the event that operating temperatures were higher than 0 °C when measured, the resulting clearance determination would err on the conservative side. The clearance requirements for trees under OHLs is measured from the maximum permissible height of vegetation which specifies an unrestricted height for vegetation of 3 m (plus surplus if available) beneath and adjacent to any OHL meeting the minimum vertical clearance requirements.

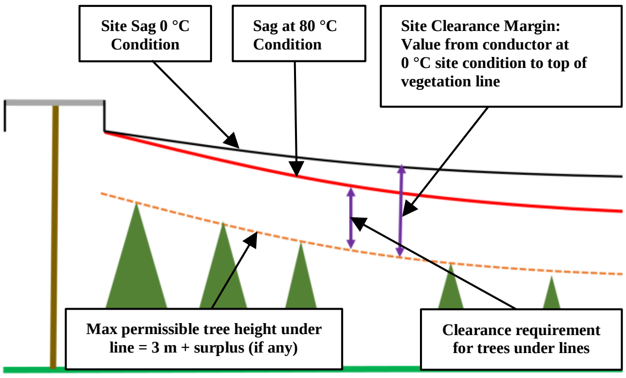


Figure 2: Site Clearance Margin

The site clearance margin made it possible to relate vegetation heights to everyday site sag conditions at typical operating temperature ranges and permitted the classification of the risk of undergrowth grow-in to OHLs. These vegetation clearance requirements were reviewed and a suite of practical guidelines were developed which defined risk-assessed clearance zones as Standard, Urgent or Emergency. These classifications were based on conservative assessments of vegetation growth provided by lidar surveys over consecutive years.

Falling Tree Risk

Vegetation falling onto, or coming into contact with OHLs or their supports poses a significant risk to network reliability. Consideration must be given to the falling distances of trees along the OHL corridor to ensure appropriate clearances are provided. Horizontal swing out, which refers to the distance a conductor moves laterally from the origin of the outer conductor under the high wind or the combined wind and ice weather cases, is critical in ensuring adequate tree clearance corridors are specified. With regards to falling tree risk, the combined wind and ice weather condition was found to be the most significant when calculating the horizontal swing out zone. The maximum limits of the combined wind and ice condition also represents a critical position which forms the boundary between the falling tree and grow-in zones.

The revised approach for falling tree risk also provides an allowance for positive transverse cross-slopes of up to 10 per cent gradient. This mitigates a risk under the existing approach whereby falling trees may come in to contact with the OHL in cases where the ground elevation of the tree base is greater than that under the OHL. Another significant improvement on the existing vegetation management approach is outlined in Figure 3 whereby the measured height of the conductor (A) from ground level is used as a means of determining the horizontal swing out zone (B). This subsequently permits the maximum permissible height of vegetation to be extended out to the limits of the horizontal swing out zone. Beyond this distance, (B), the maximum permissible height of vegetation (C) depends on the projection of a line at 45 ° from the intersection points of the dimensions (B) and (C).

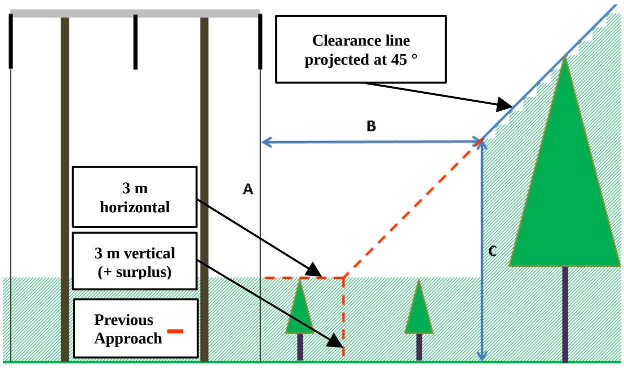


Figure 3: Comparison of previous and revised approaches

Grow-in Risk

Undergrowth grow-in refers to the risk associated with vegetation beneath or adjacent to the OHL growing vertically upwards and infringing the minimum clearance requirements based on growth over a period of time. This poses a significant risk to OHLs as it can occur under calm air conditions with the conductor at maximum operating temperature (typically 80 °C) or when the conductor is loaded under the ice-only weather case. Grow-in can also present risks under both high wind, and combined wind and ice weather conditions if vegetation within the horizontal swing out zone makes contact with an OHL under blown out conditions.

In order to manage vegetation grow-in, a risk-assessed approach for managing vegetation clearance violations on OHLs was developed based on measured values for annual growth in Ireland. This approach classifies the danger vegetation grow-ins pose to OHLs based on the specification of risk levels for infringements on the clearance margin at the maximum design temperature condition. It is possible to relate these clearance requirements to normal line operating temperatures due to the calculation of the site clearance margin.

A maximum vegetative growth rate of 1.4 m per annum was obtained from a statistical assessment of vegetation growth rates measured with lidar over successive growth periods. Standard, Urgent and Emergency risk classifications, as outlined in Table 2, were defined based on this growth rate to manage vegetation grow-in beneath and adjacent to the OHL. These risk classified zones apply for a lateral distance from the outer phase conductor determined by the horizontal swing out zone and consider both the clearance requirements for trees under OHLs and the minimum phase to earth clearance (D_{EL}) outlined in EN50341-1:2012 [8] to form a clearance envelope. These classifications permit a consistent approach to risk-assessing vegetation grow-ins and provides a prioritisation for mitigation measures based on projected growth rates.

Table 2: Risk Classified Clearance Zones for (All Voltages)

Classification	Infringing Lower Bound of Clearance Zone By	Mitigation Measure for Vegetation
Standard	Less than 0.7 m	Cut within 12 months if growth up to 0.7 m
Urgent	Between 0.7 m and 1.4 m	Cut within 6 months if growth up to 1.4 m
Emergency	Between 1.4 m and D_{EL} for voltage level	Cut within 1 month if growth up to D_{EL}

The Standard, Urgent and Emergency zones are illustrated in Figure 4. The classification of these risk zones is dependent on the maximum operating temperature and the site measured sag of the conductor (assumed to be at 0 °C) when the vegetation survey took place.

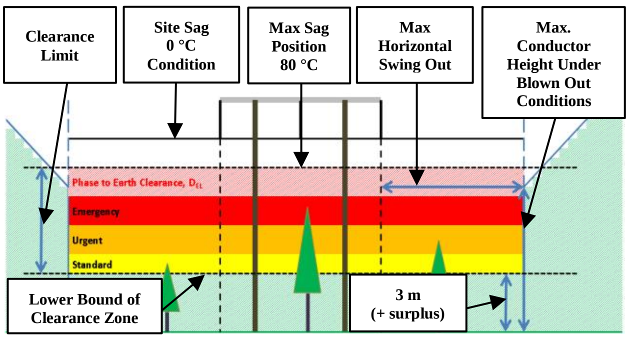


Figure 4: Revised Risk Classified Zones

The trees located within the clearance envelope and situated in the Standard, Urgent and Emergency zones must be cut according to the guidelines in Table 2. The revised risk-assessed clearance zones require more extensive timber cutting compared to the existing approach as illustrated in Figure 5 which shows an actual lidar vegetation cross-section overlain on the clearance zones. This has the added benefit of reducing the risk of undergrowth grow-in along the line which might violate the minimum clearance requirements.

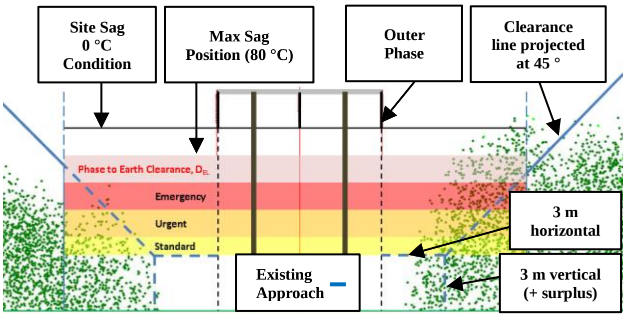


Figure 5: Previous Approach to Assessing Cutting Requirements

CASE STUDY

The development of the TRDM application and the revised clearance requirements from OHLs to vegetation, terrain and other obstacles culminated in their combined application on a potentially highly loaded 110 kV line in Ireland. The line is 41.7 km long and contains over 200 spans of varying length. Constructed in the 1950s, the line is strung with a 300 mm^2 (Lion) ACSR conductor, large sections of which have the original conductor still in place.

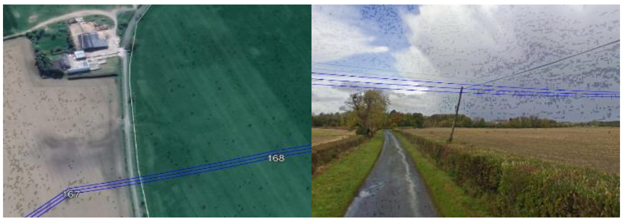
A rapid thermal assessment was required to identify any potential or existing clearance issues which might be present along the OHL following concerns regarding high loading and hot conductor joints. The TRDM application facilitated the quick and accurate organisation of line source data obtained following a lidar survey of the line for analysis by the thermal rating function in the design software. An assessment of the clearance requirements from the OHL to vegetation along the line corridor considering the revised clearance requirements was also performed through the design software.

A total of 22 clearance infringements from terrain and other obstacles were identified. These ranged from Low and Medium risk clearance issues to more serious High and Extreme risk clearance violations identified under the high temperature (80 °C) weather case. Table 3 highlights the most serious of these clearance violations which were in the High and Extreme risk categories. An example is shown for span 167-168 which has been classified as a High risk due to a road crossing. This location is also in proximity to farm buildings as shown in Figure 6.

Table 3: Clearance Violations from Terrain and Obstacles

Span	Radial Clearance Margin	Obstacle	Risk Classification
151 - 152	-1.12 m	Road	Extreme
200 - 201	-1.73 m	Farmland	High
105 - 106	-0.75 m	Road	High
167 - 168	-0.58 m	Road	High

Further clearance violations were noted under the moderate and heavy ice load conditions. These clearance infringements were classified as Low or Medium risk and occurred between the OHL and low or medium voltage crossings.



(a) (b)

Figure 6: Aerial Image (a) and Isometric View (b) of Ground to OHL Clearance Infringement at Span 167-168.

A vegetation clearance assessment evaluating locations where vegetation is deemed to pose both grow-in and falling tree risks to the OHL was also undertaken using a geospatial model created with the design software. This report assessed the risks to the OHL, under the revised vegetation clearance criteria to allow targeted vegetation clearance/cutting to take place. As noted, management of sheltered vegetation corridors along the OHL is important in mitigating the reduced cooling effects of low wind speeds. This is of particular concern where dead-end positions and mid-span joints on lines with relatively old conductors may be positioned with consequent risk of elevated temperatures potentially reducing the lifespan of the hardware and/or conductor. A total of nine separate sheltered corridors were identified along the line route occurring at the structures as shown in Figure 7, and also at mid-span positions.

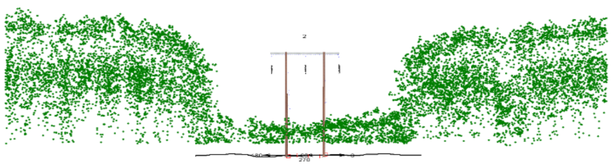


Figure 7: Vegetation Clearance Infringements at Structure

The risk posed by the vegetation to the OHL was classified as Standard, Urgent and Emergency in accordance with the criteria set out in Table 2. A report was prepared and issued to the utility asset manager which outlined the clearance infringements identified from the assessment process. Other mitigation measures recommended to overcome the clearance violations included line re-sagging, structure alterations and a targeted vegetation clearance approach.

CONCLUSIONS

The use of technology is important in allowing efficient and effective asset management decisions to be made. An in-house application called the TRDM was developed to handle and organise line-load and meteorological data corresponding to lidar surveys of OHLs. This permits large datasets to be processed by the design software's thermal rating calculator and for clearance infringements, based on an estimate of the conductor temperature, to be identified.

A rapid clearance assessment was required on a 110 kV OHL considered to have a high loading. On inspection of the OHL, concerns were also raised in relation to the presence of sheltered or partially sheltered spans. Through utilisation of the TRDM application, a review was undertaken which considered the clearance requirements from terrain and obstacles in addition to the revised clearance requirements from OHLs to vegetation. A number of risk-assessed clearance infringements were identified following the assessment process. This allowed targeted mitigation measures to be recommended. The results were well received by the asset manager and highlights the innovative and productive approaches being employed for OHL asset management in Ireland to ensure continued public safety and network reliability.

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