WESTERN POWER DISTRIBUTION
INNOVATION

NEXT GENERATION NETWORKS

Improved Statistical Ratings for DNO Overhead Lines

CLOSEDOWN REPORT

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Contents

Executive Summary

The thermal ratings applied to the UK's distribution network overhead lines are determined by national standards developed over 30 years ago. These ratings are probabilistic, meaning that there is a finite risk that a conductor could exceed its design temperature when subjected to full, rated load. They are also seasonal, varying in line with average temperatures within each season.

With overhead line ratings being dependent on prevailing weather conditions, there was a concern that climate change may have had an impact over the last 30 years. In addition, recent work has cast doubt on some of the assumptions made within the rating standards currently in use.

This project was undertaken to update the thermal model used to calculate overhead line ratings along with the assumed relationship between the thermal ratings and the associated risks of design temperatures being exceeded. This has been achieved with the use of a test rig, constructed at WPD's Stoke depot. Data obtained over a two-year period has been analysed and incorporated into a new software tool for calculating overhead line ratings.

A key finding of the project has been that the seasonal boundaries defined by existing standards are not representative of real conditions: instead of three distinct seasons (summer, winter, and a combined spring/autumn), the project found that a 4-season split was more representative, with the seasons not necessarily being made up of contiguous months.

The next key finding of the project was that existing ratings are conservative in the summer months (i.e. there is scope to increase ratings while maintaining currently assumed risk levels) but optimistic in the winter months.

There is, however, still scope for maintaining current ratings or even raising them further in all seasons, with a better understanding of the risks. A new risk model is proposed that would allow DNO's to undertake their own assessments applicable to their networks, taking into account the specific operating conditions that apply.

The findings of this project will be implemented in an updated issue of ENA ER P27 which will be complemented by the software tool produced by the project.

The new P27 standard along with the advanced features of the software tool will provide DNO's with the flexibility they need to provide overhead line ratings for networks subject to continual change in the way they are operated.

1 Project Background

Distribution overhead line ratings are probabilistic, and based on CEGB research work and further assumptions described in ENA ACE 104 and ENA ER P27 published nearly 30 years ago. Recent work testing these assumptions has found some of them to be erroneous, with the result that existing distribution line ratings are now considered out of date. In the meantime, changing demands on networks are increasing the pressure to maximize overhead line capacity. In addition, existing ratings take no account of regional differences in climate, or of any changes in climate that may have occurred over the last 30 years. Taken in conjunction, this means that load-related decisions to replace or reinforce lines are currently based on inaccurate ratings. Future climate change is predicted to put further pressure on line capacity.

Distribution Network Operators (DNOs), therefore, need a cost-effective, up-to-date and robust methodology (supported with the necessary tools) for calculating and optimizing overhead line ratings at both the regional and line specific level, both for today and the future.

2 Scope and Objectives

This project made use of a test rig facility to gather 2 years of monitored conductor temperature and weather data. This data was analysed to validate and update overhead line ratings, update existing tools and methodologies, and produce a software tool that will enable GB DNOs to further optimise regional or line specific ratings. More specifically, the data gathered was used to update the assumed relationship between ratings and the risk of experiencing a temperature excursion (exceedance).

In addition, the feasibility of conducting an equivalent "offline" study, using conductor temperatures calculated from weather data (both directly measured and predicted) was explored, to determine if future studies could avoid the time and expense involved in setting up and running a physical test rig.

Objective	Status
To monitor the weather conditions and co-incident temperatures of various conductors at various current levels in order to provide a new dataset for the assessment of the weather risk element of probabilistic ratings and to derive a methodology for quantifying this risk, in combination with load risks, in order to calculate line ratings.	✓
To update ENA ER P27 and ENA ACE 104	✓ (Subject to ENA Process)
To validate the updated CIGRÉ methodology for calculating conductor temperature from load and weather data, allowing the possibility of future "desk top" re-runs of the project to cover different locations	✓

and time periods.	
To update existing software tools, and to provide a new software tool to enable more comprehensive (regional or line specific) rating assessments to be made.	✓
To engage with the Met Office to enable rapid provision of appropriate weather data sets.	✓

3 Success Criteria

Success Criteria	Status
Sufficient data collection to build a robust model of overhead line ratings	✓
Analysis of that data to produce a model that enables more robust rating of overhead lines than the current model	✓
A new software tool to enable more comprehensive (regional or line specific) rating assessments to be made.	✓
A robust, accurately informed revision of ENA ACE 104 and ENA ER P27.	✓ (Subject to ENA Process)

4 Details of Work Carried Out

4.1 EA Technology – Test Rig, Updated Ratings, and Software

The primary aim of this project was to update existing distribution overhead line ratings, which are given in ENA ER P27 and derived according to the methodology outlined in ENA ACE 104.

To this end, a test rig was constructed, by EA Technology, at WPD's Stoke Depot. This test rig comprised 4 circuits utilising three different conductors and energised continuously at three different current levels, with conductor temperatures and weather parameters being monitored over a two-year period. The data gathered was analysed in order to determine the statistical relationship between an overhead line conductor's rating and the associated risk of that conductor exceeding its design temperature under full rated load (the "exceedance"). This relationship, described by what is referred to as the "CT Curve", is what is used to determine a probabilistic thermal rating for an overhead line.

Full details of the work carried out by EA Technology are contained in their final report, included at Appendix A, and will not be repeated here. The conclusions drawn by EA Technology can be summarised as follows:

1) Where, previously, ratings varied according to three separate seasons (“Summer”, “Winter”, and “Normal”), they should now be varied according to four separate seasons (“Summer”, “Winter”, “Intermediate Warm”, and “Intermediate Cool”).

2) A new CT Curve was derived and incorporated into a new software application allowing seasonal ratings to be determined for any bare conductor and for any combination of rated temperature and exceedance, within reasonable limits. This software is freely available and a user guide is included at Appendix B.

3) The heat balance equations outlined in CIGRE Technical Brochure 601 are appropriate and may be used to calculate conductor temperatures from given weather parameters and current loading.

Outside the scope of EA Technology’s work, however, was a comparison of “new” and “old” ratings – such a comparison is described and discussed in Section 9 “Outcomes” of this report.

4.2 Use of Calculated Temperatures

In addition to the work done by EA Technology, the project also considered the feasibility of using conductor temperatures calculated from weather data, in place of conductor temperatures obtained from measurements on a test rig. Two sources of weather data were considered: from direct measurement and from hindcast datasets provided by third parties.

Whilst an initial comparison of measured and calculated temperatures was carried out by EA Technology, who concluded the suitability of the CIGRE TB601 methodology, a more thorough comparison was made afterwards.

In the case of the EA Technology work, only a limited sample (a single summer season) of the dataset was used. In order to get a fuller picture, the calculated temperature distribution for the whole of the 2017 calendar year was compared with the measured distribution over the same time period (Figure 1).

The same conductor / current combination (the hottest) was used, but conductor parameters adjusted to better reflect the physical reality on the test rig – EA Technology’s analysis used an emissivity co-efficient of 0.8 (the same value for fully aged conductor assumed for the standard rating calculation), whereas the test rig employed new conductor where a 0.3 emissivity co-efficient would be more appropriate. Using the hottest overall dataset for comparison would tend to maximise any errors in calculations – a close match would therefore be considered more robust.

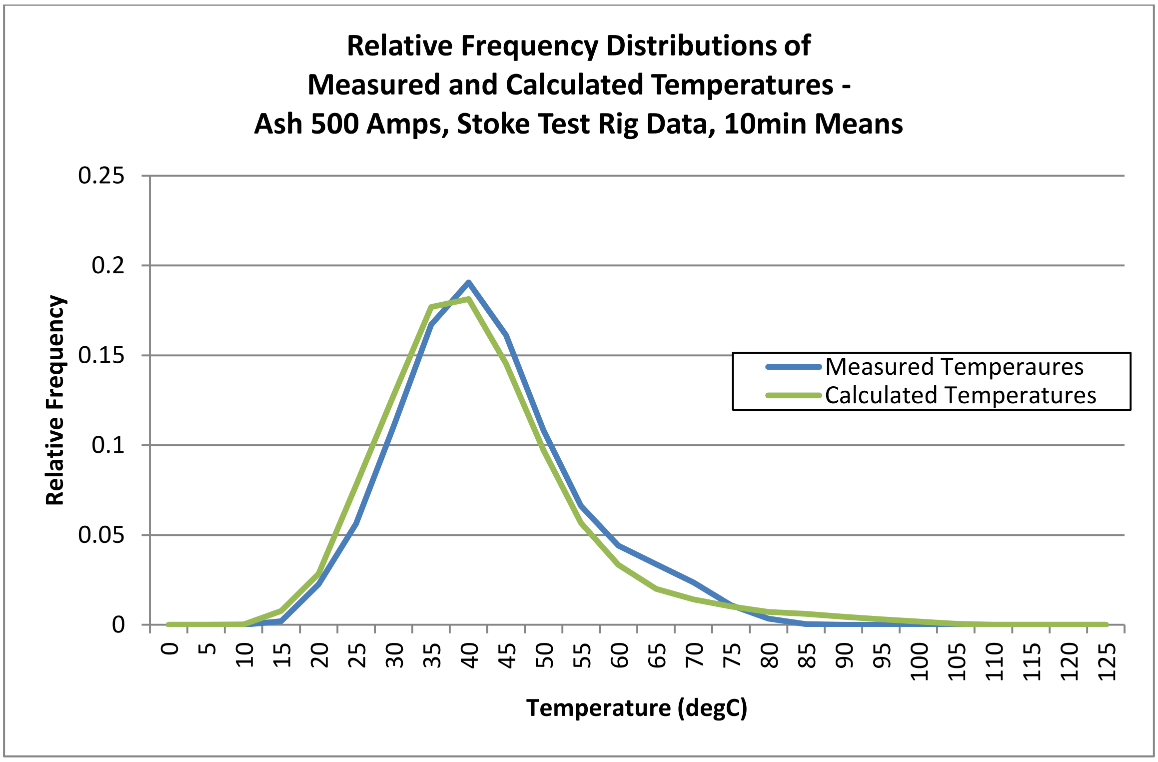

Figure 1
Comparison of Calculated and Measured Conductor Temperature Distributions

The similarity of the two temperature distributions is very encouraging; however it is noticeable that the differences become more apparent at the higher temperatures, with a noticeable tendency to underestimate temperatures in the 60°C – 75°C range, and to over-estimate above 75°C. The impact of these differences is illustrated in Figure 2.

The solid red line in Figure 2 is the CT Curve derived by EA Technology and incorporated into the rating calculation software. Each point on the scatter plot represents a CT & Exceedance combination relating to one of the conductor / current / season / temperature combinations under consideration, using the same methodology as described in EA Technology's report.

In general, where plot points lie to the right of the reference CT Curve, a higher rating would be calculated. Points to the left indicate that a lower rating would be calculated. Figure 2 indicates that where low-exceedance ratings are calculated, the result would be a lower rating, whereas for higher exceedances the rating calculated would be higher.

Distribution ratings would typically lie around the 1-3% exceedance level meaning that if a CT Curve was derived from this project's weather data alone, slightly higher ratings would result. If those ratings were to be applied, they would carry a higher real risk than assumed from calculations. Whether this is would be problematic or not is hard to tell – the reference curve derived from measured data lies (mostly) within the scatter of the calculated values.

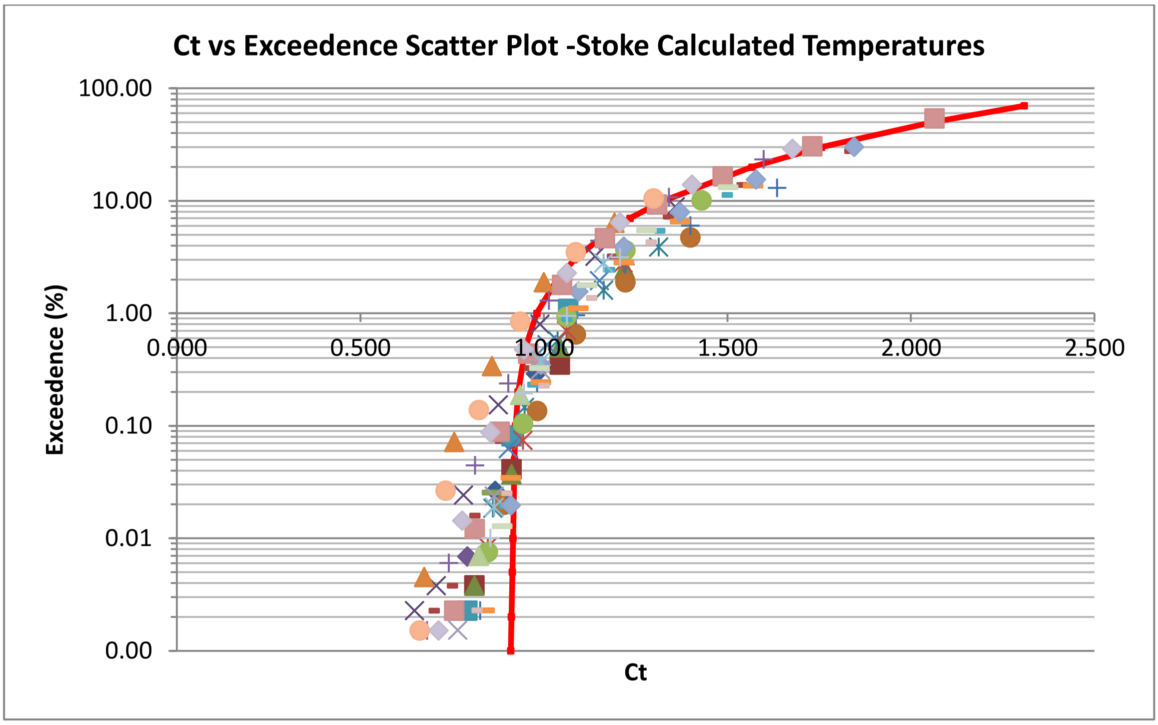

Figure 2
Comparison of CT Curves derived from Measured and Calculated Data from Test Rig

Examination of the conditions giving rise to the highest discrepancies between measured and calculated temperatures indicates that errors are highest when weather conditions are both changeable and when they yield the poorest cooling. This is because the temperature calculation is "quasi static" – the heat balance equations are solved for the steady state solution for each row of weather data. When each row represents a 10 minute mean, for example, the conductor is treated as if it reaches its final, steady state temperature subject to those weather conditions within 10 minutes. This is not, in reality, the case when cooling conditions change rapidly from one 10 minute period to the next. The conductor will take time to heat up or cool down.

Although outside the scope of this project, using a dynamic thermal model is therefore likely to yield significant improvements in accuracy when calculating temperatures based on time-series weather data.

4.3 Use of Third Party "Hindcast" Weather Data

As well as using weather data obtained directly from the Stoke test rig, the project also sought to establish the feasibility of using third party "hindcast" data – site specific historical data sets derived from UK-wide weather stations.

Two organisations were approached: the Met Office and Digital Engineering. The Met Office are long established in the field of weather data provision and were an obvious choice, while Digital Engineering have recently begun to provide site-specific weather data to National Grid to aid with overhead transmission tower design.

Each organisation provided a 10 year historical dataset of hourly mean ambient temperatures and solar radiation values. Each organisation then provided the wind speed value used within their respective models, along with (at the request of the Project Champion) the minimum 10 minute mean wind speed value. The different values are summarised below:

Organisation	Wind Speed Data Provided
Met. Office 1	"Top-of-hour" 10 min mean
Met. Office 2	Minimum 10 min mean within the hour
Digital Engineering 1	Hourly Mean
Digital Engineering 2	Minimum 10 min mean within the hour

The time period covered by each dataset varied, too. The Met Office provided data for 2005 to 2014 inclusive, while Digital Engineering provided data from 2007 to 2017 (initially 2007 to 2016, but the 2017 year was obtained to ensure at least one full year's overlap with a hindcast dataset and the Stoke dataset). The Met Office were able to provide data after 2014, but a change in their base model meant that years after 2014 would be calculated on a different basis. The 2005 to 2014 time period was therefore chosen in the interests of consistency. While climate change has been a factor, it was felt that the 2-year offset between the two datasets would have a negligible effect.

The batch-run functionality of the EA Technology software was then used to calculate a conductor temperature distribution for each of the four datasets above, and were compared with similar distributions derived from the weather data acquired by the Stoke test rig. Two distributions were calculated from the Stoke data: one using hourly means of all weather parameters, and another distribution based on the same data but using the minimum 10 min mean wind speed within each hour. The results are presented in Figure 3, with the measured temperature distribution provided for reference.

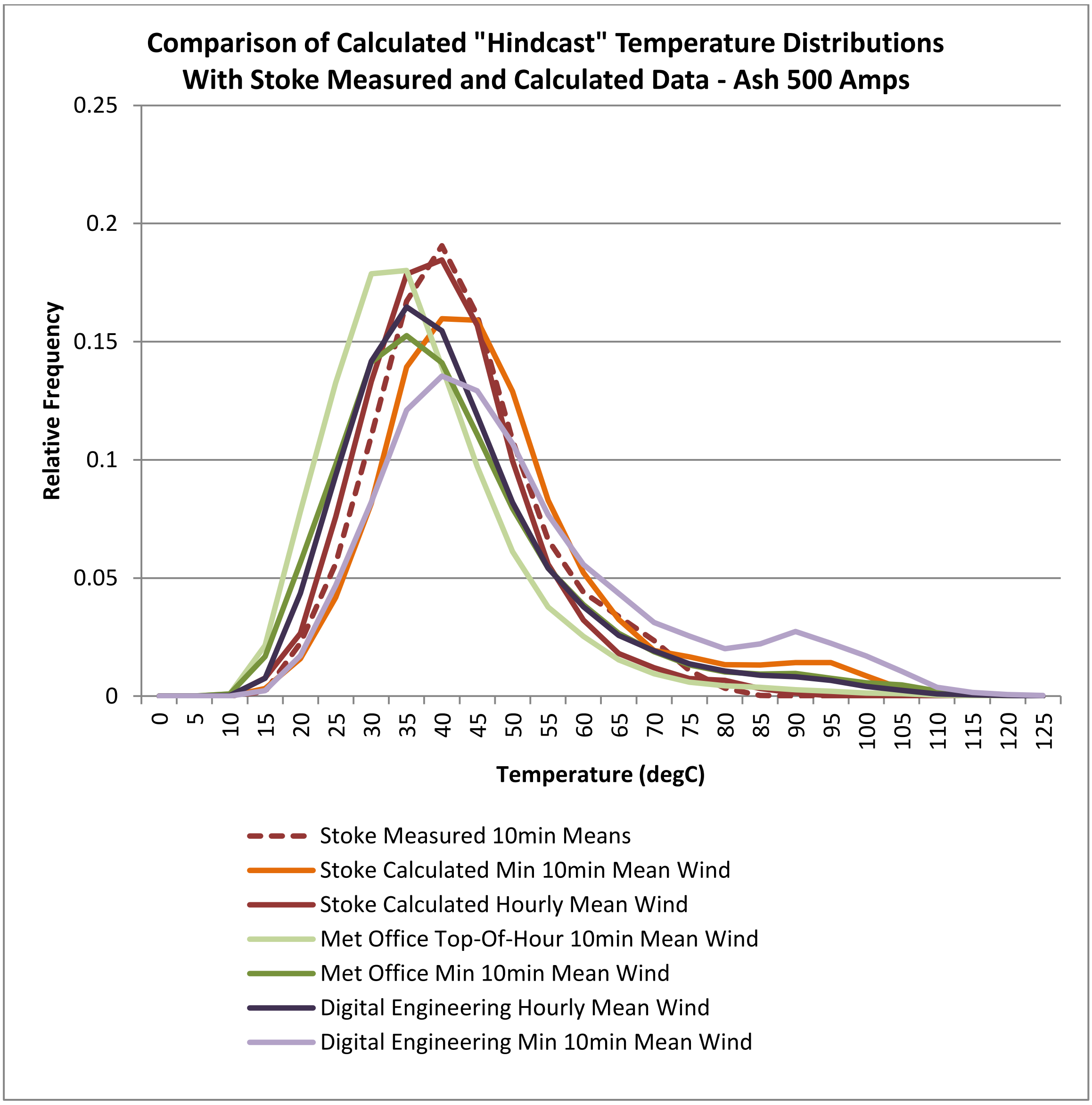

Figure 3
Comparison of Hindcast Data with Stoke Measured Data

Whilst it is not surprising that the closest match to the Stoke measured temperature distribution comes from temperatures calculated from weather measured at the same time and location, what is interesting is that the closest match comes from temperatures calculated from hourly mean wind speeds, not minimum wind speeds. In fact, there is essentially no difference between the distributions of hourly means to the 10 minute means.

There is, however, a wide scatter in the hindcast distributions and in some unexpected areas – the Digital Engineering hourly mean values are a close match to the Met Office minimum 10 min mean values.

While a certain amount of deviation from the Stoke reference data is to be expected (there is very little co-incident data involved), the variability between the different datasets would indicate they are not suitable, on their own, for conducting an “off line” alternative to this project, as there is no way of determining if there is a bias in the data. At the very least, the hindcast dataset would require some sort of benchmark dataset for comparison.

However, this does not mean that such datasets are not of value: studies based on comparative values are likely to prove more reliable, for example when assessing the probabilities of co-incident weather conditions at two locations or, potentially, assessing the impact of a changing climate.

5 Performance Compared to Original Aims, Objectives and Success Criteria

Objective: Monitoring weather parameters and conductor temperatures; derive methodology to quantify risk
Success Criteria: Sufficient data collection to build a robust model of overhead line ratings
Status: Completed / Success

The test rig was first energised at the beginning of January 2016, and was de-energised at the beginning of January 2018. For the most part the rig operated as expected with only minor issues arising. However, over the summer period there was a catastrophic failure of a power factor controller resulting in a small fire within the porta cabin housing the power supplies. While the associated equipment was not destroyed, there was sufficient damage caused to result in a three-month shutdown of the test rig. Despite this three-month period of no data being acquired, the test rig was able to gather data for a continuous 16-month period which is considered to be sufficient for reliable conclusions to be drawn from analysis of the data, and for the building of a robust model of overhead line ratings.

Objective: To validate the updated CIGRÉ methodology for calculating conductor temperature from load and weather data, allowing the possibility of future "desk top" re-runs of the project to cover different locations and time periods.
Status: Completed / Success

Early analysis of data acquired by the rig involved using measured weather data in conjunction with the known current flowing through the conductors in order to determine, by calculation, the conductor's temperature. To achieve this, the methodology and equations detailed in CIGRE Technical Brochure TB601 were used, the result being compared to the conductor temperatures obtained by measurement.

The result of this analysis successfully indicated that TB601 could safely be used to calculate conductor temperature from weather and current loading data, although a more in-depth analysis than that carried out by EA Technology indicated results were likely to be conservative. Greater accuracy is likely to be achieved with a modification to the calculation methodology.

Success Criterion: Analysis of that data to produce a model that enables more robust rating of overhead lines than the current model
Status: Completed / Success

Once data acquisition was completed, the continuous dataset covering the calendar year of 2017 was analysed using the same basic methodology as that used by the CEGB in order to establish a “CT Curve” - the relationship between expected “exceedance” (the probability of a conductor being hotter than its design temperature when subjected to full rated load), and the rating assigned to it for a given set of standard parameters. In contrast to the original CEGB work, which made assumptions about seasonal boundaries that have been shown to be unrepresentative of today’s climate, this analysis was carried out at monthly granularity, so that those seasonal boundaries could be more reliably determined.

The results of this analysis have allowed new seasonal boundaries to be defined which are felt to be truly representative of today’s UK climate and, together with the newly established relationship between “exceedance” and rating, has resulted in an improved rating model allowing a more robust derivation of overhead line ratings.

Objective: To engage with the Met Office to enable rapid provision of appropriate weather data sets
Status: Completed / Partial Success

In line with the project objectives, location specific weather data sets (for the Stoke test rig site) tailored to the specific requirements of calculating conductor ratings were obtained from two external providers: the Met Office and Digital Engineering. These hindcast datasets gave hourly values for both average and minimum wind speeds along with co-incident values of ambient temperature and solar radiation.

A rough comparison of the data received with data logged by the test rig showed that all the datasets gave reasonable agreement with the overall pattern of weather conditions, which is encouraging, but there were significant variations in the calculated conductor temperature distributions derived from the datasets which indicates they may not be suitable for use in deriving new CT curves. However, it is likely that comparative studies using such datasets could still be of benefit.

Objective: To update existing software tools, and to provide a new software tool to enable more comprehensive (regional or line specific) rating assessments to be made.
Success Criterion: A new software tool to enable more comprehensive (regional or line specific) rating assessments to be made.
Status: Completed / Success.

A Software application has successfully been produced to provide the core functionality of being able to calculate probabilistic conductor ratings and/or deterministic conductor temperatures from relevant input parameters. In addition, the application allows batch runs to be performed on imported datasets, allowing a user to determine ratings and/or temperatures from time-series weather datasets. The resulting output can then be analysed in any way the user sees fit. If new “CT Curves” are derived, the software allows the user to define new curves in order to calculate bespoke probabilistic ratings.

Objective: To update ENA ER P27 and ENA ACE 104
Success Criterion: A robust, accurately informed revision of ENA ACE 104 and ENA ER P27.
Status: In progress / Success

The project’s final reports (this report in conjunction with EA Technology’s final report) will take the place of ENA ACE 104, while a revision to ER P27 will be subject to ENA timescales. The suggested framework for a revised P27 is contained in this report, and has been presented for consideration by the ENA Overhead Line Panel.

6 Required Modifications to the Planned Approach during the Course of the Project

One aspect of the rating risk model has had to be adapted during the course of the project: it was originally envisaged that a typical / standard load duration curve could be derived and incorporated directly into the “exceedance” value for line ratings. However, with the recent advances in smart network technologies such as Active Network Management and other network control schemes, it was decided that a standard load duration curve derived for this project would soon be out of date or inappropriate. It has, therefore, been decided that the “exceedance” assigned to line rating would be representative of weather variability only.

7 Project Costs

Activity	Budget	Actual
EA Technology Costs		
Electricity North West	£80,808.00	£80,808.00
Northern Powergrid	£86,467.00	£86,467.00
Scottish and Southern Energy	£91,125.00	£91,125.00
SP Energy Networks	£90,294.00	£90,294.00
UK Power Networks	£100,110.00	£100,110.00
Western Power Distribution	£105,824.00	£105,824.00
Other DNO Costs and Contingency	£192,926.00	£74,705.21 *
Total	**£747,554.00**	**£629,333.21**

*Underspend due to some costs lower than anticipated, including weather data.
Total contingency budget also not used, no further follow-up work was required.

8 Lessons Learnt for Future Projects

The vast majority of the time allocated to this project has been spent on the operation and maintenance of the test rig, and the acquisition of data. For the most part, this activity went very well, with the exception of the catastrophic power supply component failure. This failure led to a redesign of some aspects of the test rig, such as the use of components with metallic, rather than plastic, covers, and the use of higher-rated components and forced ventilation to avoid over-heating problems.

With a relatively short period of time in which to analyse the data, speed has been of the essence. What has helped has been frequent updates and face-to-face meetings with EA Technology to ensure that this last, and most crucial, phase of the project remained focussed and on track for a timely completion.

Software development, however, proved more challenging in terms of timescales than initially thought. While a functional software application was delivered on time, there was still a significant period of bug-fixing and optimisation that followed. A key learning point here is that development of software should start as early as possible to allow more time for the inevitable bugs to be found and fixed.

9 The Outcomes of the Project

The high level outcome of the project is that DNOs are now able to calculate probabilistic ratings that represent today’s UK climate. The precise effect on the ratings assumed in ENA ER P27 will vary according to the conductor type, the rated temperature, the season, and the exceedance level chosen.

In broad terms, this project has shown that the summer ratings of P27 are conservative, with the new ratings being higher. Conversely, it appears that winter ratings have been optimistic, with new ratings being lower.

What used to be referred to as the “normal” season, combining both autumn and spring is now two, separate seasons reflecting the variation between these “intermediate” months. Ratings in the cooler of these months have been shown to be about right, while the warmer of these months have generally been optimistically rated.

These changes are not unexpected – previous work undertaken as part of the Strategic Technology Programme indicated an elevated risk of temperature excursions compared with P27, predominantly in the winter, with a much lower risk in the summer.

These new results, however, do not necessarily mean that DNOs must immediately de-rate their overhead lines. The exceedance levels quoted against ratings do not represent the real risk of a temperature excursion – to be more precise they represent the risk that the prevailing weather conditions cannot provide the assumed rating. In order for an overhead line to exceed its rated temperature, it must also experience a load that is high enough to exceed its real-time rating. By better understanding this risk, ratings with a higher exceedance could be chosen while maintaining acceptable overall risk levels.

It is worth noting that the UK distribution networks have been utilising the ratings of P27 for a very long time, with no adverse consequences.

The assumptions made in ENA ACE 104 in determining the acceptable exceedance levels for ratings are highly conservative and not necessarily applicable today. A Strategic Technology Programme project reviewed ACE 104 and sought to investigate the impact of using typical load duration curves from today's distribution networks. The conclusions were that there was significant scope for increasing ratings.

To illustrate what is achievable; tables 1 and 2 below illustrate the impact of the new ratings on two, typical cases: a 50mm^2 "Hazel" AAAC rated at 50degC on the 11kV network, and a 150mm^2 "Ash" AAAC rated at 50degC on the 33kV network.

Applying the new ratings on a like-for-like exceedance basis, summer ratings would all rise, while the rest would all fall. Moving to a 3% rating for the 11kV network, however, would result in rating increases in all seasons. The acceptability of moving from the 0.001% to the 3% rating clearly needs to be established. On the 33kV, a move to a 6% exceedance level would negate most rating decreases, while a move to a 9% exceedance would yield ratings increases in all seasons. Again, the acceptability of these higher exceedances needs to be established.

Table 1
Comparison of Ratings (Amps) Given by New Software and Existing P27

	11kV Hazel @ 50degC				33kV Ash @ 50degC		
	New	P27	Change		New	P27	Change
	0.001%	0.001%	(%)		3%	3%	(%)
Summer	175	165	6		410	397	3
Iwarm	182	191	-5		426	460	-7
Icool	192	191	0		450	460	-2
Winter	196	206	-5		460	494	-7

Table 2
Comparison of Ratings (Amps) Required by New Software to Match Existing P27

	11kV Hazel @ 50degC				33kV Ash @ 50degC		
	New	P27	Change		New	P27	Change
	3%	0.001%	(%)		6%	3%	(%)
Summer	191	165	16		433	397	9
Iwarm	198	191	4		450	460	-2
Icool	210	191	10		476	460	4
Winter	214	206	4		486	494	-2

These potential changes are further complicated by the fact that DNOs are increasingly adopting "smart" network control systems such as Active Network Management and Flexibility Services in place of traditional asset reinforcement. The wider application of such systems will mean that there will no longer be a "typical" load duration curve, meaning that real exceedance risk levels will vary not just by the type of network (described in P27 as "primary distribution" or "secondary distribution") but also by area, depending on the application of active network controls.

In order to ensure all lines can be rated reliably, DNOs will need the flexibility to determine the acceptable exceedance potentially on a line-by-line basis. Where lines are being pushed to their limits for prolonged periods of time, it makes sense to adopt lower exceedance ratings. Where lines are only expected to see high loads after rare circuit faults, higher exceedance ratings may be applied.

It is therefore proposed that a more detailed risk model is developed, and captured in a revised ENA ER P27. The aim would be to move away from a P27 document that stipulates the exceedance levels to be chosen and instead provide a framework for DNOs to apply their own risk models. Even the fault rate and duration data of ENA ACE104 varies significantly from region to region, and yet the ACE104 data has been assumed as universal.

A proposed risk model for consideration by the ENA for inclusion in a revised P27 is given in Appendix C.

Unfortunately, the work undertaken to assess the feasibility of using conductor temperatures calculated from weather data in order to be able to repeat the project for different time frames and locations without the need for a physical test rig has not yielded any firm conclusions.

While a move to a dynamic, rather than static, thermal model is likely to improve the comparison between measured temperatures and temperatures calculated from measured values, it has not been possible to put this theory to the test. However, with the Stoke datasets readily available, it would be beneficial for a small project to investigate the use of a dynamic thermal model.

The use of third-party hindcast datasets to determine new CT curves, however, does not appear to be advisable, although comparative studies might yield more reliable results. Such studies might determine the risk, for example, of wind speed being high at a wind farm location at the same time as being low at an overhead line location.

10 Data Access Details

The full datasets from the Stoke test rig have been compiled into a suitable format for distribution, as have the datasets from the Met Office and Digital Engineering.

The software tool developed by this project is available for download, as is the source code.

www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx)

11 Foreground IPR

The datasets and software developed as deliverables of this project are freely available, along with the software's source code.

The software tool has been developed under a variant of the Creative Commons License, allowing free sharing and free adaptation.

The final, published ENA ERP27 will have copyright assigned to the Energy Networks Association.

12 Planned Implementation

The primary implementation of this work will take the form of an updated issue of ENA ER P27. Periodic updates on the progress of this project have been presented to members of the Overhead Line Panel so that the ENA process can commence with publication of this report. Feedback from Panel members on the proposed risk model has been positive.

Within WPD, new ratings have already been compiled for use in network studies – WPD's Network Strategy team are currently assessing the South Wales EHV network. The final exceedance levels to be chosen still need to be decided, but it is likely that, where network analysis tools allow, different exceedances will be applied to different network conditions, giving different "pre-fault" and "post-fault" ratings.

WPD are also planning to apply the new seasonal boundaries determined by EA Technology's work to the ratings assigned to other assets such as underground cables and transformers.

13 Contact

Further details on replicating the project can be made available from the following points of contact:

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Glossary

Abbreviation	Term
CEGB	Central Electricity Generating Board
CIGRÉ	The International Council on Large Electric Systems
Quasi Static	Thermodynamic process that happens slowly enough for the system to remain in internal equilibrium.
AAAC	All Aluminium Alloy Conductor
Flashover	Near-simultaneous ignition of most of the directly exposed combustible material in an enclosed area. When certain organic materials are heated, they undergo thermal decomposition and release flammable gases.

Appendix A

EA Technology – User Guide: Integrated Ratings Software Tool

To request a copy of this report, please email wpdinnovation@westernpower.co.uk.

Appendix B

EA Technology – Improved Statistical Ratings for Distribution Overhead Lines (Phase 2) Final Report.

A copy of this report can be found on Western Power Distribution's website here: www.westernpower.co.uk/innovation/projects/improved-statistical-ratings-for-distribution-overhead-lines

Alternatively, a copy of the report can be downloaded from this link: www.westernpower.co.uk/downloads/29896

Appendix C

A Proposed Risk Model For Overhead Line Ratings

The exceedances stipulated by the current version of ENA ER P27 were determined according to the methodology described in ENA ACE104. A key condition that this document sought to meet was that the annual probability of a line experiencing a temperature excursion should be limited to 1×10^{-6}. This is a highly conservative approach that does not fully represent the risk that DNO's are seeking to avoid: the risk of flashover occurring as a result of a thermal event.

Within reason, simply having a conductor exceed its design temperature is typically of negligible consequence. A flashover, however, could have severe consequences. Broadly speaking, a flashover will occur if three conditions are met:

1) There must be an infringement of design clearances sufficient to result in the breakdown of the air. The probability of this occurring is described as P(Clear).

2) This clearance infringement must be to a "limit state" obstacle – for example the clearance requirement over a road caters for vehicles up to 5m in height. Such vehicles are generally only under an overhead line very briefly. The probability of such an obstacle being present is described as P(Obstacle).

3) The voltage on the overhead line conductor must be the highest catered for in the design of the line. "Normal" power frequency voltage is often not the voltage actually used to determine clearances and insulation requirements. At higher nominal operating voltages, for example, insulation is specified so as to cater for switching surges, with clearances designed to match. This probability of maximum voltage being present is described as P(Volts).

Further to (1) above, a clearance infringement requires two conditions to be met:

4) The conductor must exceed its design, profile temperature – the probability being described as P(Temperature).

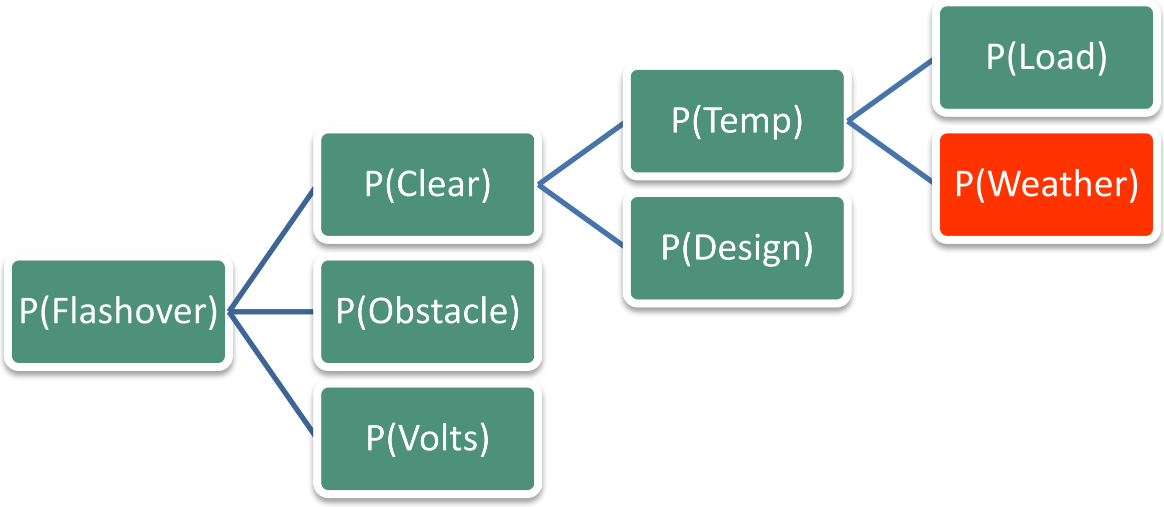
5) The temperature rise must be sufficient to overcome any excess clearance available – the majority of overhead line spans, once constructed, afford greater clearances than those required simply due to the constraints placed on designers, such as where structures can be placed. This probability is described as P(Design).

Further to (4) above, the temperature exceedance also requires two conditions to be met:

6) The conductor must be carrying a load current greater than the maximum current that would result in a zero exceedance – i.e. the load current must be greater than that determined by the absolute worst set of cooling conditions that a line might experience. This probability is described as P(Load).

7) Finally, the prevailing weather conditions must be insufficient to provide a real time rating greater than the load current. This probability is described as P(Weather)

Graphically, this risk model can be represented as follows:



In the context of work undertaken in this project, P(Weather) is the exceedance associated with a calculated rating.

While some generic assumptions could sensibly be made for P(Obstacle), P(Volts), and P(Design), and P(Weather) can reliably be chosen as a result of this project, the most variable and uncertain parameter above is P(Load).

Depending on the type of network, P(Load) could be dependent on a variety of factors. At one extreme, a single circuit connecting a conventional generator could be subject to full load continuously, with P(Load) = 1. Alternatively, there could be a circuit on the EHV network that might only see maximum load after two circuit outages, where P(Load) could be as low as 10^{-3}.

In the context of this proposed framework, DNO’s could undertake their own assessment of risk, particularly of P(Load), and choose rating exceedances accordingly.