WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

Updated Probabilistic Thermal Ratings of Distribution Overhead Lines

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Outline

- NIA Project Summary

- Outline of Rating Methodology

- NIA Project Progress & Early Results

- Application of Ratings - Building a Risk Model

- Application of Ratings – Enhanced Application

- Next Steps

NIA Project – Summary

- Aim: to provide DNO's with up-to-date, reliable, and flexible overhead line ratings

- Duration: 3 years – July 2015 to June 2018
  - Including 2 years' data acquisition

- Main deliverables:

  - Update ENA ER P27 (nationally applicable ratings)

  - Software tool to provide DNO flexibility in derivation and application of ratings

Background - OHL Ratings Today

- UK overhead line ratings are probabilistic, and given in ENA ER P27

- They are expressed as having a certain "exceedence" - the risk of a conductor exceeding its design temperature

- The "3%" rating, for example, carries a 3% chance of a conductor's temperature rising above its design temperature when full rated current is applied

Background - Calculation of Ratings

- Probabilistic ratings are calculated by applying a scaling factor to a reference rating – a rating calculated from a reference set of weather conditions by applying standard heat balance equations

- A function linking the scaling factor to the desired risk level was derived by experiment by the CEGB, Leatherhead, in the late 1970s / early 1980s
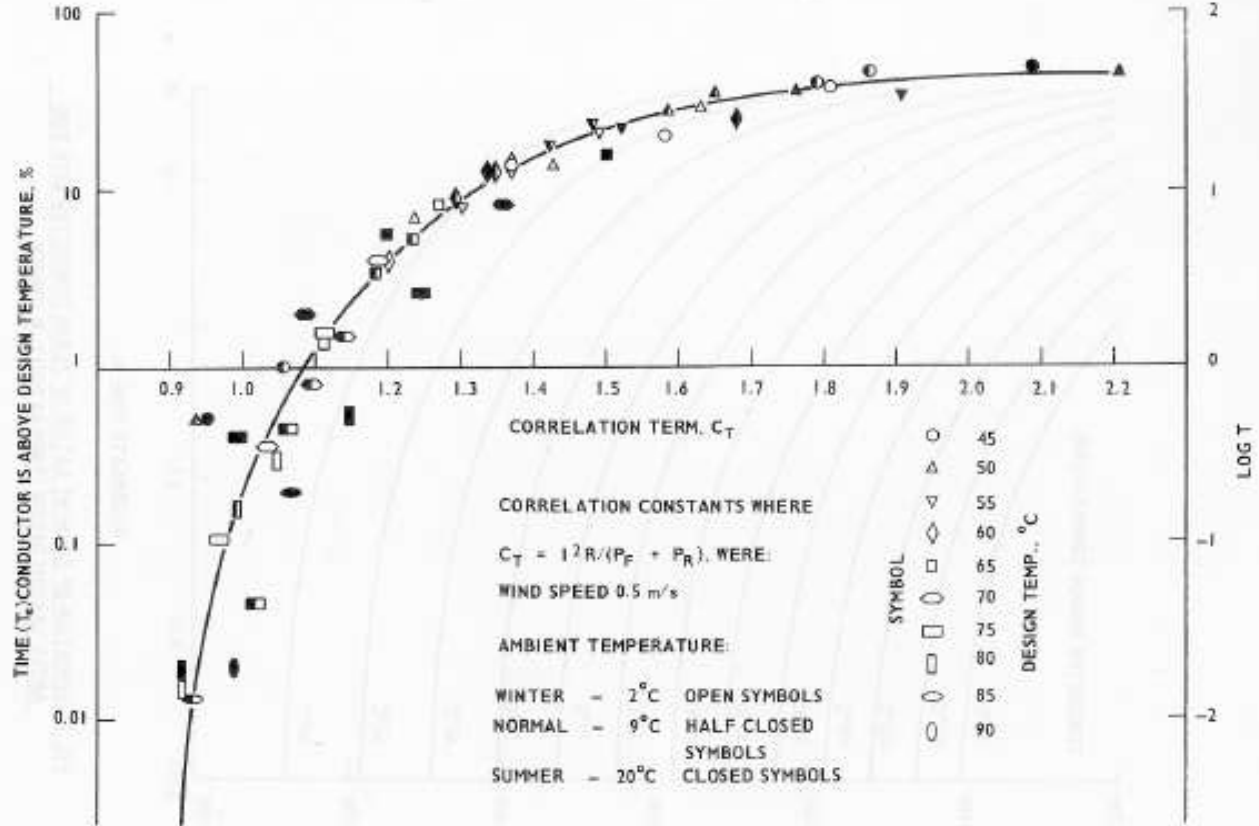
CERL
C_T vs T_e

FIG. 1 CORRELATION OF ZEBRA TEMPERATURE EXCURSION DATA FOR THE SEASONS AND FOR VARIOUS DESIGN TEMPERATURES

NIA Project – Problem (1)

- Recent work carried out as part of the Strategic Technology Programme concluded that assumptions used in the CEGB work were erroneous

- A changing climate over the last 35+ years has further invalidated that original work

- ENA ER P27 is no longer considered reliable

NIA Project – Project Aim (1)

- To redefine the function linking reference rating to probabilistic rating
  - Same basic methodology as used by CEGB
  - Designing the experiment to minimise the need for problematic assumptions (e.g. seasonal boundaries)
  - Outcome to allow more reliable UK overhead line ratings to be calculated
- Deliverable: Updated ENA ER P27

NIA Project – Problem (2)

- Climate continues to change with time, and is variable geographically
  - Experimentally derived function highly unlikely to remain valid indefinitely
  - Function could also be adapted to different regions
  - Repeating the experiment is very expensive and time consuming
- The ability to re-run the experiment "virtually" would be very beneficial

NIA Project – Project Aim (2)

- Deliverable: A software tool allowing DNOs the flexibility to produce tailored ratings
  - With weather data and/or current load profiles as inputs, conductor temperature profiles can be calculated
  - Regional or even line specific ratings could be derived, incorporating load profiles if desired
  - Weather data could be logged locally, or produced by specialist provider (hindcast)

NIA Project – Progress (1)

- Test rig constructed at WPD's Stoke Depot
  - 4 circuits / 3 conductor sizes continuously loaded at 3 different current levels for 2 years
  - Conductor temperatures, Ambient temperature, Wind Speed, and Wind Direction monitored
- 2-year monitoring period was completed January 2018

Test Rig

- Located at WPD Stoke depot
  - Considered broadly representative of UK 11kV

- 4 Circuits, 30m spans, each energised at constant current

- Weather monitoring
  - Ambient Temperature
  - Wind Speed
  - Wind Direction
  - Solar Radiation
  - Rainfall

- Embedded thermocouples for conductor temperature measurement
  - Arranged in trios, mid-span

Test Rig Circuits

Circuit	Current	Conductor	Summer "P27" Temp	Normal "P27" Temp	Winter "P27" Temp
1	380	2 x 50 Hazel	58.1	46.8	39.6
		150 Ash	55.6	44.6	37.5
2	500	175 Elm	72.1	61.2	54.2
		150 Ash	84.1	73.4	66.4
3	440	2 x 50 Hazel	72.3	61.1	53.8
		150 Ash	68.7	57.8	50.7
4	440	175 Elm	59.6	48.7	41.6
		150 Ash	68.7	57.8	50.7

NIA Project – Progress (1) cont.

- Analysis of data has lead to a better picture of seasonal boundaries
  - Using 4 seasons instead of 3 indicated as more appropriate.
  - New reference weather parameters
  - New, universal "Ct" curve linking reference rating to probabilistic rating

Seasonal Boundaries

- Choices should be relevant to network studies - Network models assume seasonality of loads correlated with weather & climate

- Choices should minimise variability of risk within and across seasons

- Absolute accuracy of getting the months right not necessary if network loading and prevailing weather are correlated

Seasonal Boundaries

"Old" Seasons

	Winter			Normal*		Summer				Normal*		
P27 Ambient	2			9		20				9		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
UK 71 to '00	5.1	4.3	4.5	6.2	7.9	11.0	13.7	16.2	16.0	13.6	10.3	7.0
		4.6		7.1			14.2				10.3	
UK 81 to '10	4.7	4.6	4.6	6.5	8.4	11.4	14.1	16.4	16.2	14.0	10.6	7.3
		4.6		7.5			14.5				10.6	

"New" Seasons

	Winter			Intermediate (Cool)			Summer			Intermediate (Warm)		
Stoke Measured	3.6			6.6			14.3			11		
	Dec	Jan	Feb	Mar	Apr	Nov	Jun	Jul	Aug	Sep	Oct	May
UK 71 to '00	5.1	4.3	4.5	6.2	7.9	7.0	13.7	16.2	16.0	13.6	10.3	11.0
		4.6			7.0			15.3			11.6	
UK 81 to '10	4.7	4.6	4.6	6.5	8.4	7.3	14.1	16.4	16.2	14.0	10.6	11.4
		4.6			7.4			15.6			12.0	

Seasonal Boundaries - Summary

- Old
  - Winter: Dec / Jan / Feb
  - "Normal": Mar / Apr / Sep / Oct / Nov
  - Summer: May / Jun / Jul / Aug
- New
  - Winter: Dec / Jan / Feb
  - Intermediate (Cool): Mar / Apr / Nov
 - Intermediate (Warm): Sep / Oct / Apr
  - Summer: Jun / Jul / Aug

Reference Weather Parameters – P27

- Wind Speed: 0.5 m/s
- Wind Angle: 12.0° **
- Solar: 0
- Ambient:
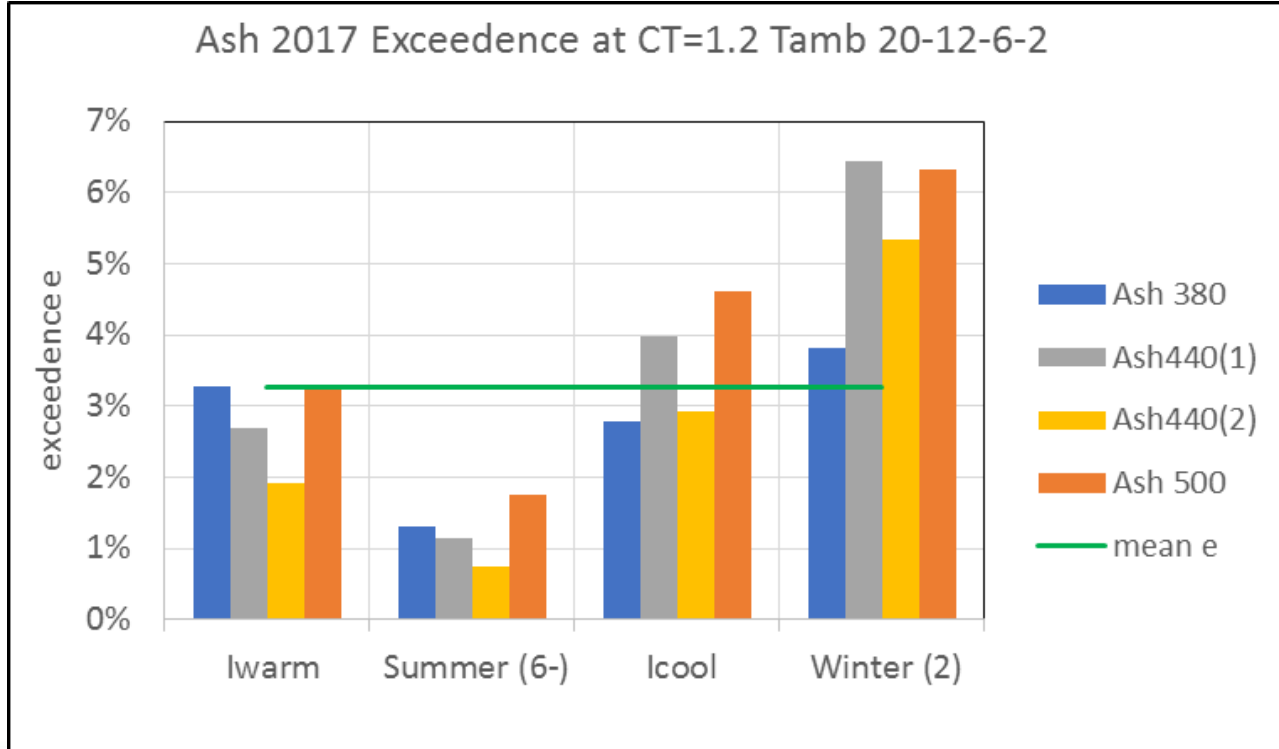 - Winter: 2 °C
  - "Normal":   9 °C
  - Summer: 20 °C

Reference Weather Parameters – New (initial)

- No change to wind & solar

- Use a "sensible" guess for new seasonal ambient:
  - Winter: 2 °C
  - Intermediate (cool):   6 °C
  - Intermediate (warm):   12 °C
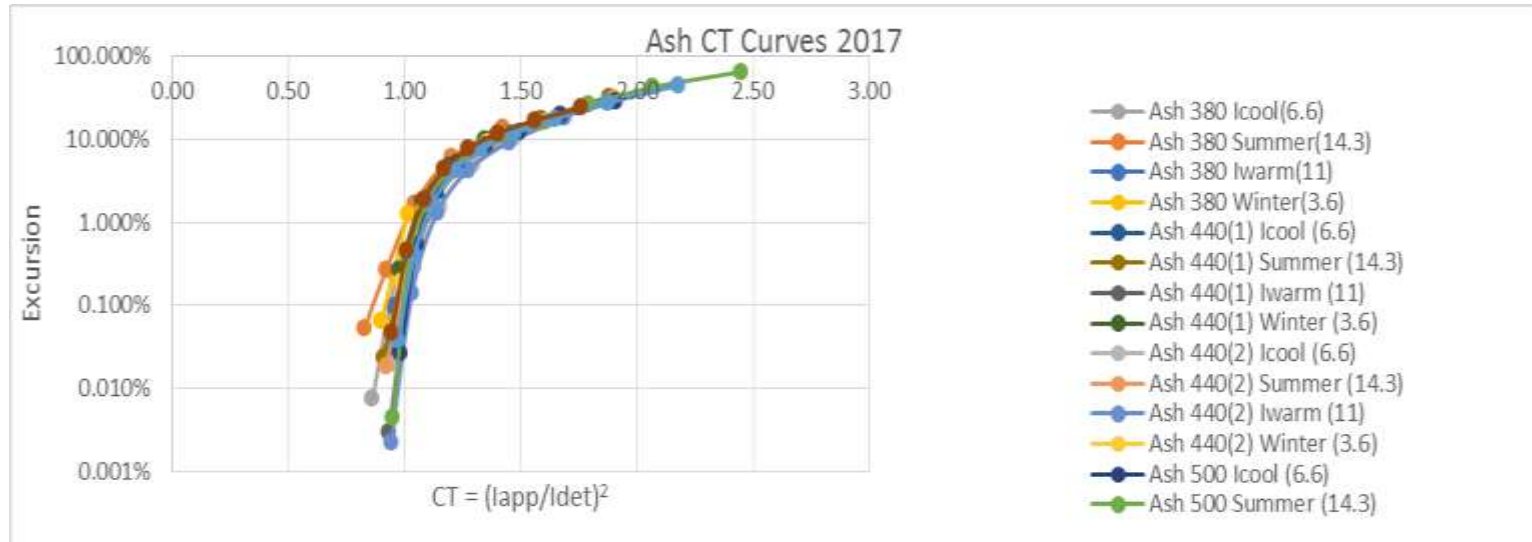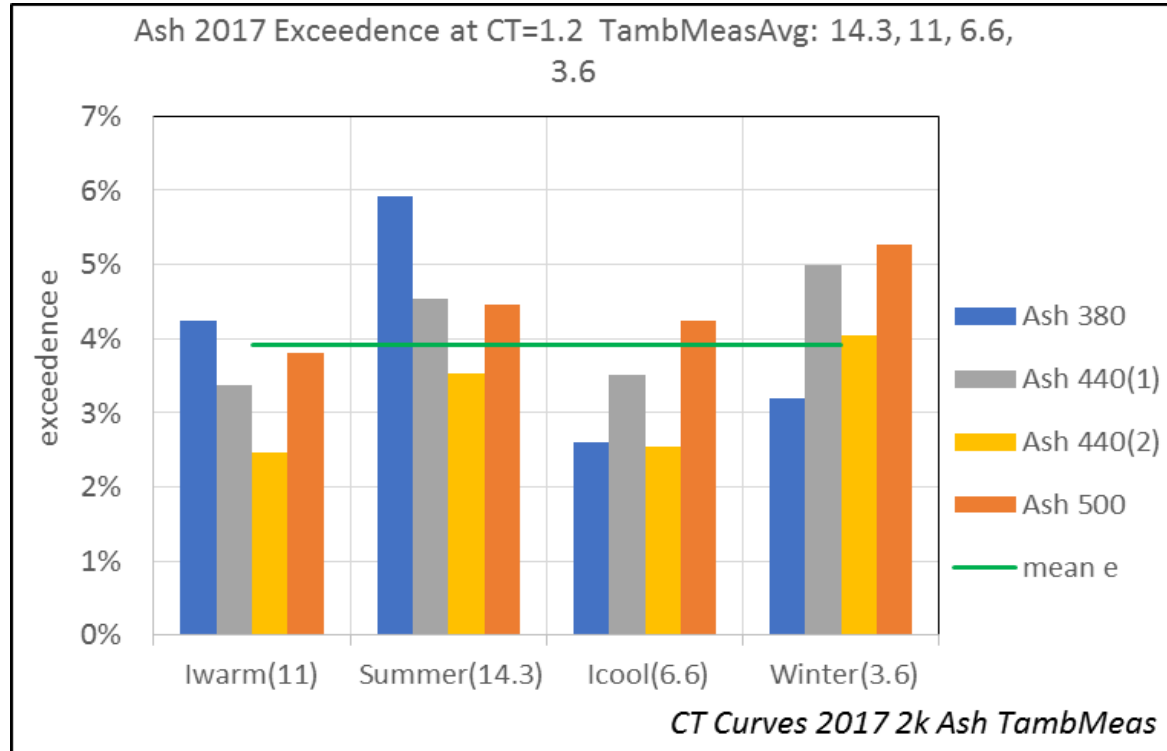 - Summer: 20 °C

# C$_T$ vs T$_e$ Curves – Guessed Ambient
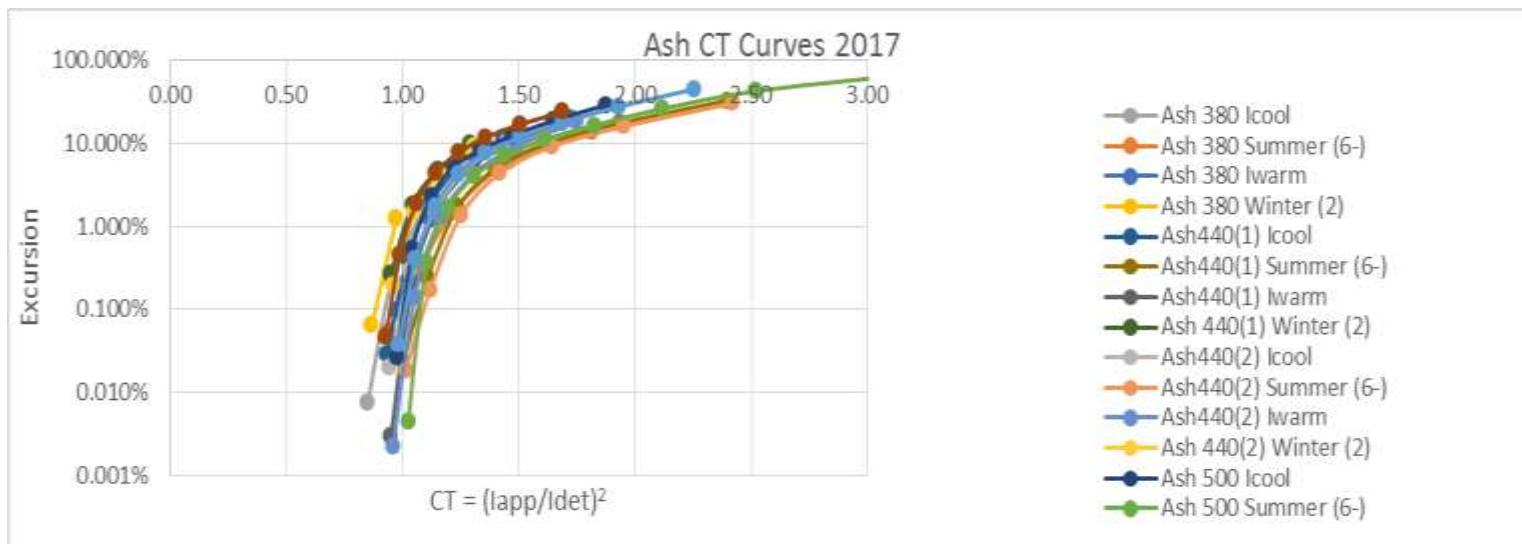
Excursions – Guessed Ambient

Ash 2017 Exceedence at CT=1.2 Tamb 20-12-6-2

Reference Weather Parameters – New (improved)

- No change to wind & solar

- Use Stoke measurements for new seasonal ambient:
  - Winter: 3.6 °C
  - Intermediate (cool):   6.6 °C
  - Intermediate (warm):   11 °C
  - Summer: 14.3 °C

C$_T$ vs T$_e$ Curves – Measured Ambient

Excursions – Measured Ambient

Reference Weather Parameters – Final

- Using Stoke ambient measurements to derive reference ratings results in C_T vs T_e curves with minimal scatter
  - This shouldn't be unexpected
- Using UK long term averages will result in more scattered curves, but this should be expected
  - Annual, seasonal variations are to be expected
- View is that UK long term averages are most appropriate, and provide a clear basis for future reviews

Reference Weather Parameters – Final

- Ambient
  - Winter: 4 °C
  - InterCool: 6 °C
  - InterWarm: 11 °C
  - Summer: 14 °C
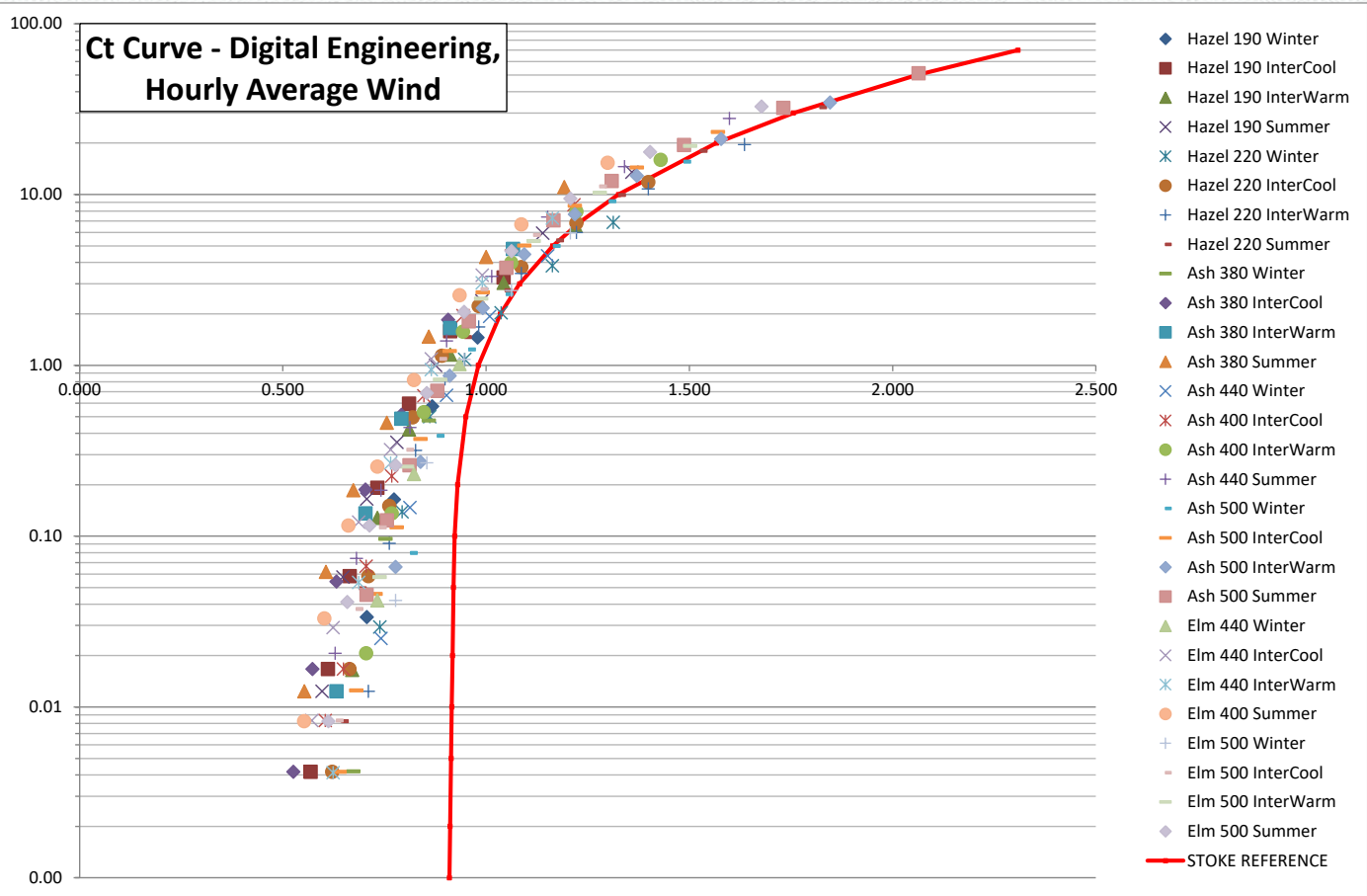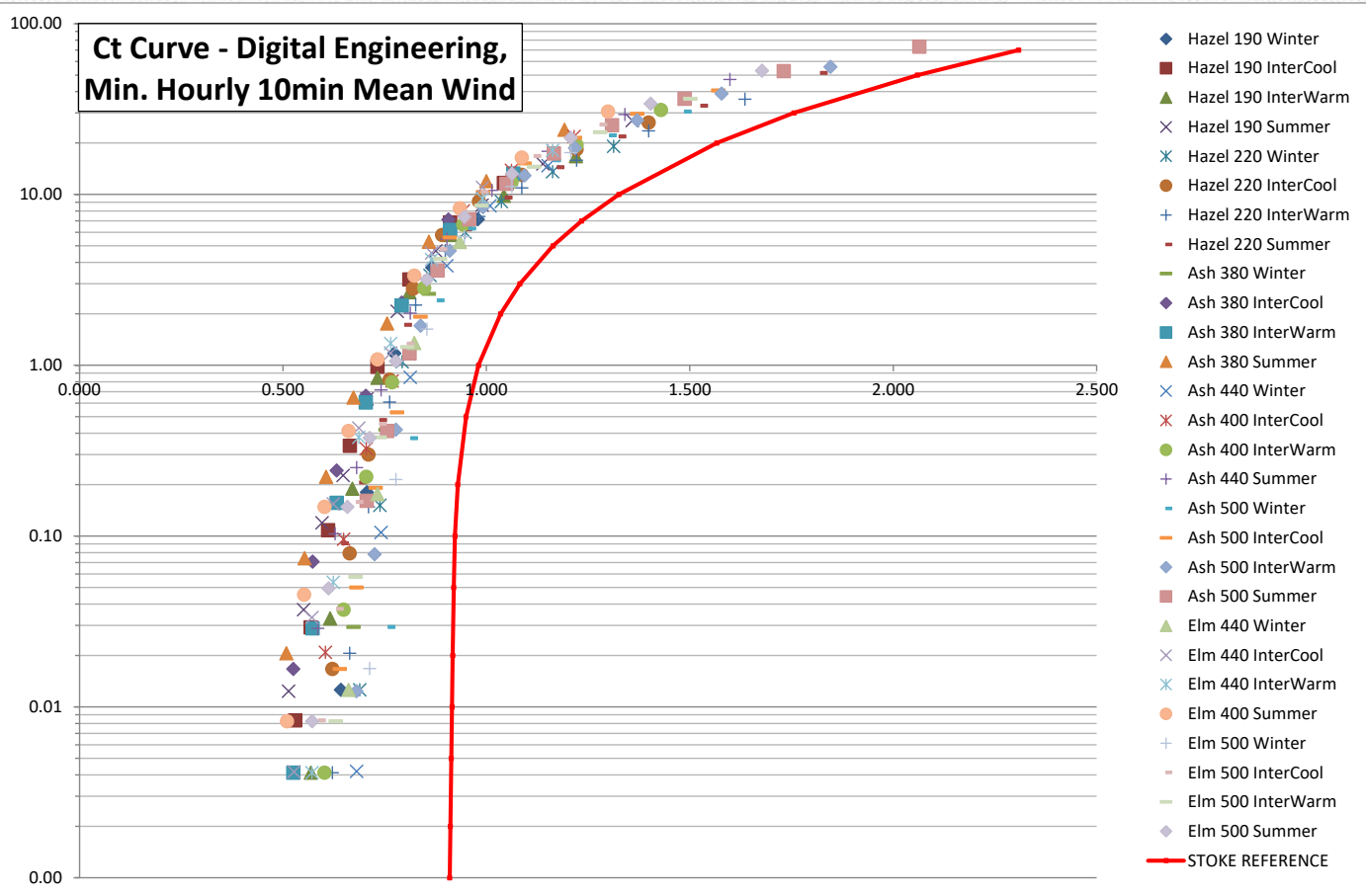- Wind: 0.5m/s @ 12° Angle of Attack
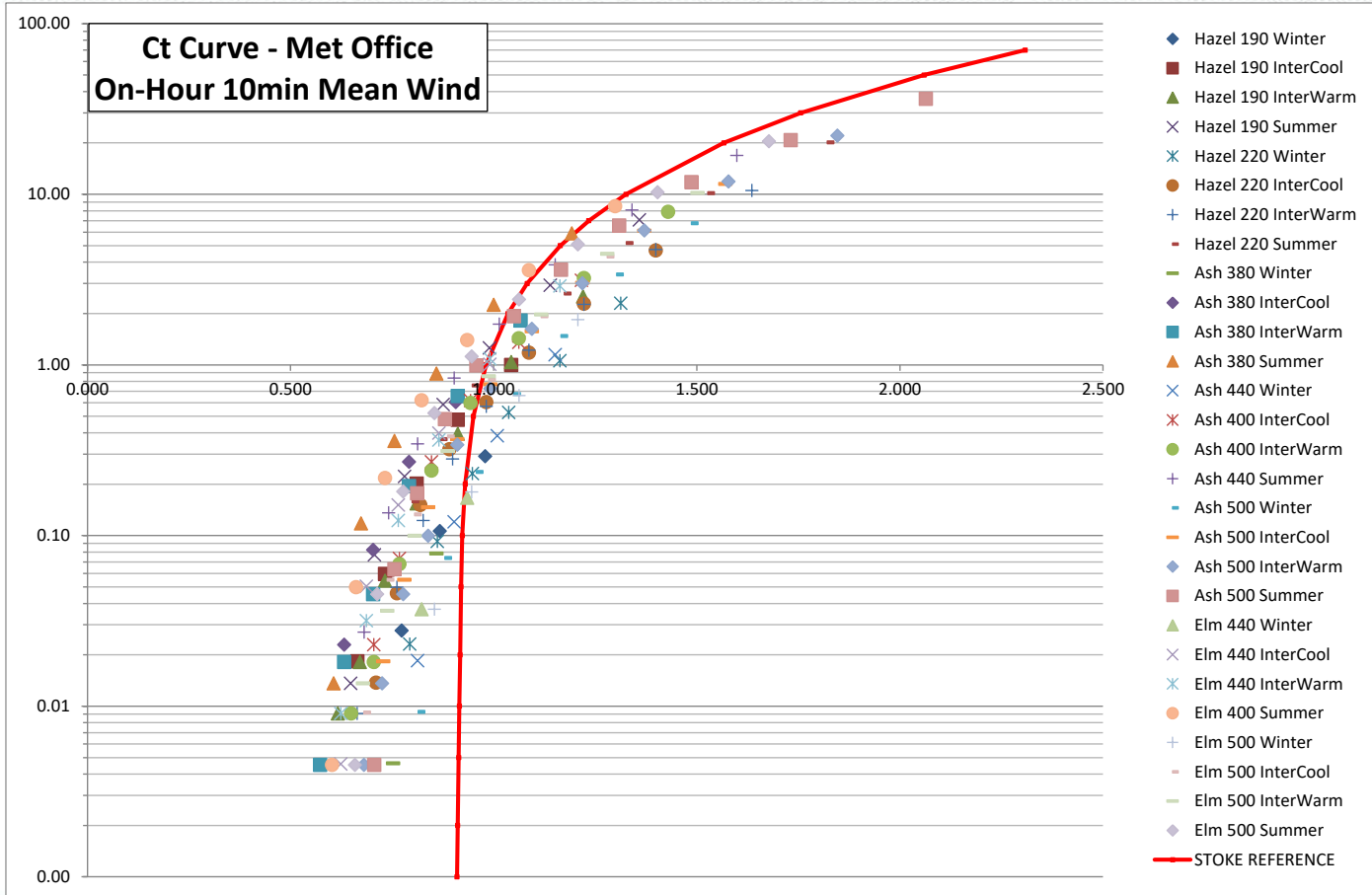- Solar: 0 W/m^2
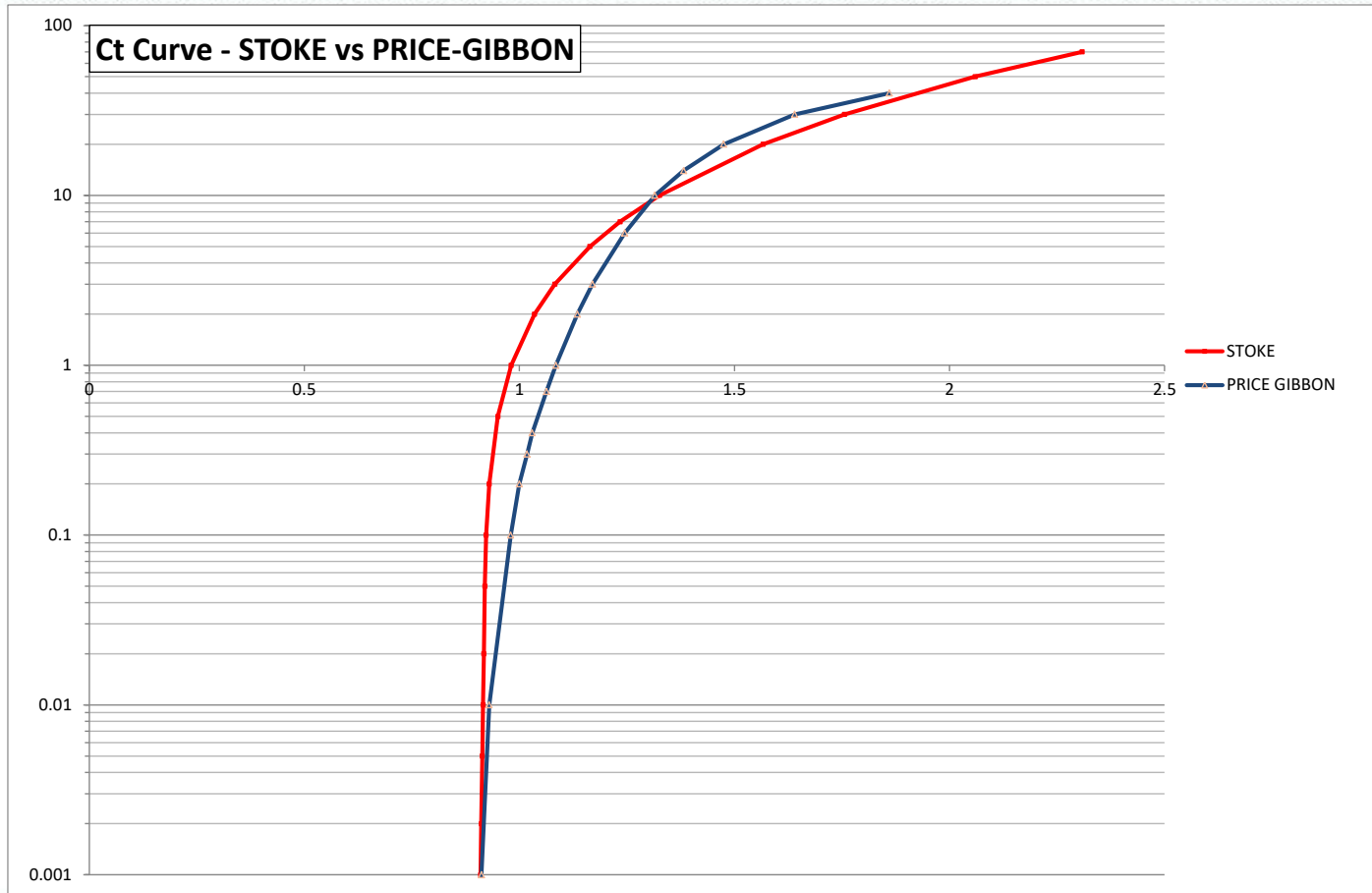
NIA Project – Progress (2)

- Logged data used to successfully validate heat balance equations & temperature calculation methodology

- Software code completed allowing conductor temperatures and reference ratings to be calculated

  - Code initially used for data analysis, subsequently incorporated into software tool deliverable
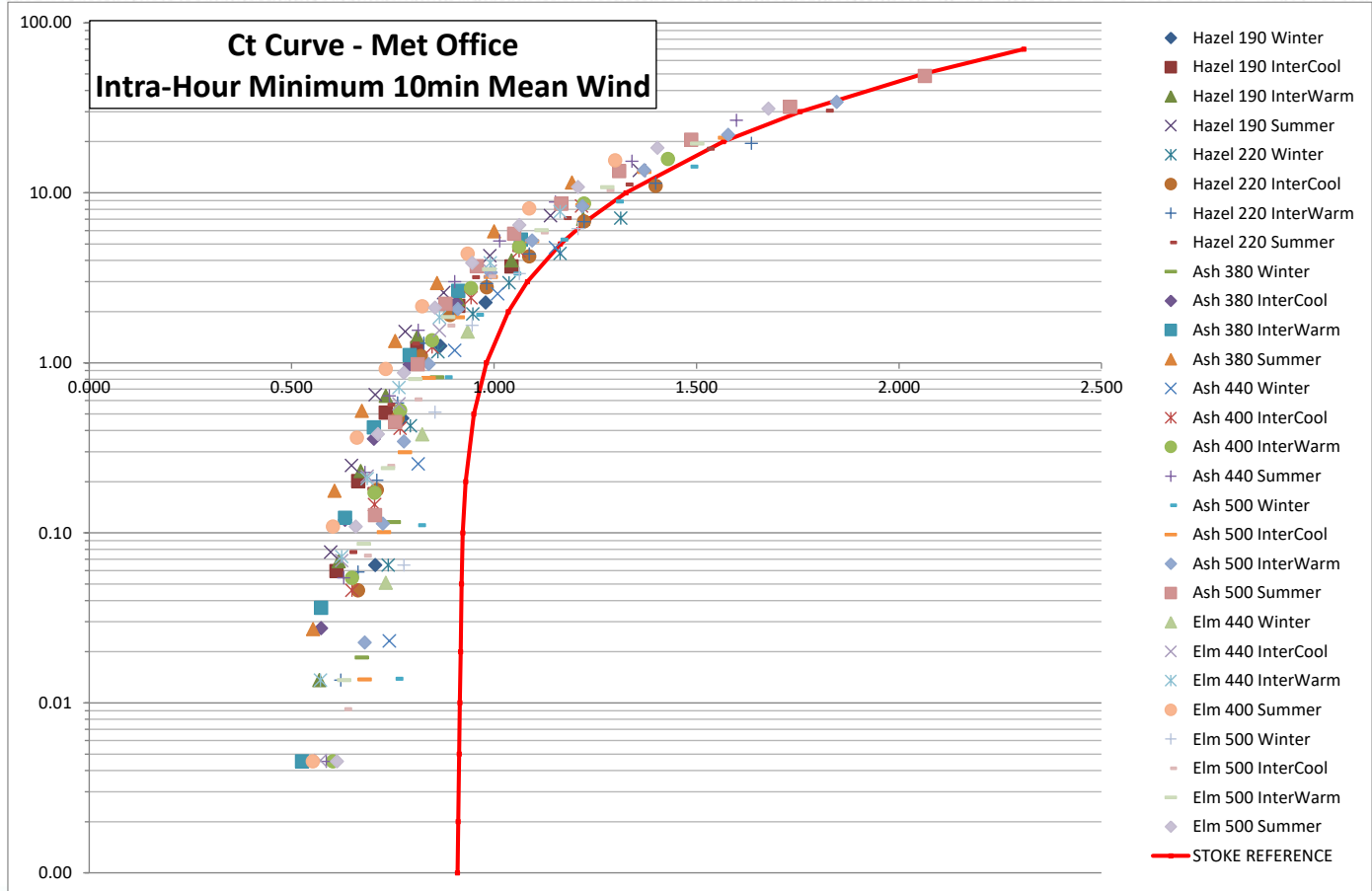
Hindcast Datasets & Calculated Temperatures

- "Hindcast" datasets procured from both Met Office and Digital Engineering

- Digital Engineering dataset coincident with Stoke experiment

- Ct curves derived from new reference weather parameters and calculated conductor temperatures

Ct Curve - Digital Engineering, Hourly Average Wind

Legend:
- Hazel 190 Winter
- Hazel 190 InterCool
- Hazel 190 InterWarm
- Hazel 190 Summer
- Hazel 220 Winter
- Hazel 220 InterCool
- Hazel 220 InterWarm
- Hazel 220 Summer
- Ash 380 Winter
- Ash 380 InterCool
- Ash 380 InterWarm
- Ash 380 Summer
- Ash 440 Winter
- Ash 400 InterCool
- Ash 400 InterWarm
- Ash 440 Summer
- Ash 500 Winter
- Ash 500 InterCool
- Ash 500 InterWarm
- Ash 500 Summer
- Elm 440 Winter
- Elm 440 InterCool
- Elm 440 InterWarm
- Elm 400 Summer
- Elm 500 Winter
- Elm 500 InterCool
- Elm 500 InterWarm
- Elm 500 Summer
- STOKE REFERENCE

Ct Curve - Digital Engineering, Min. Hourly 10min Mean Wind

Ct Curve - Met Office
Intra-Hour Minimum 10min Mean Wind

Ct Curve - Digital Engineering, 2017 Hourly Average Wind

Ct Curve - Digital Engineering, 2017 Min. Hourly 10min Mean Wind
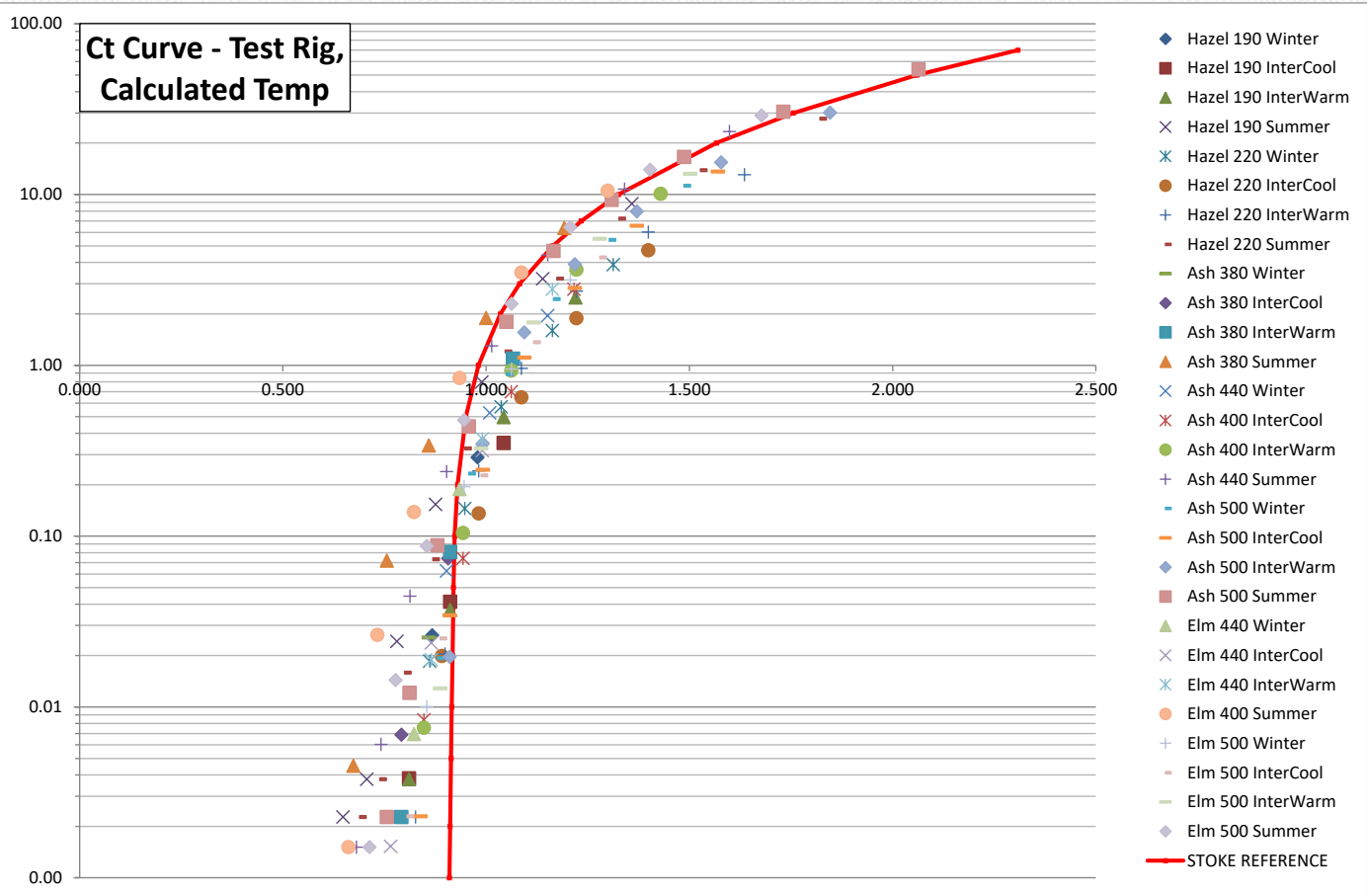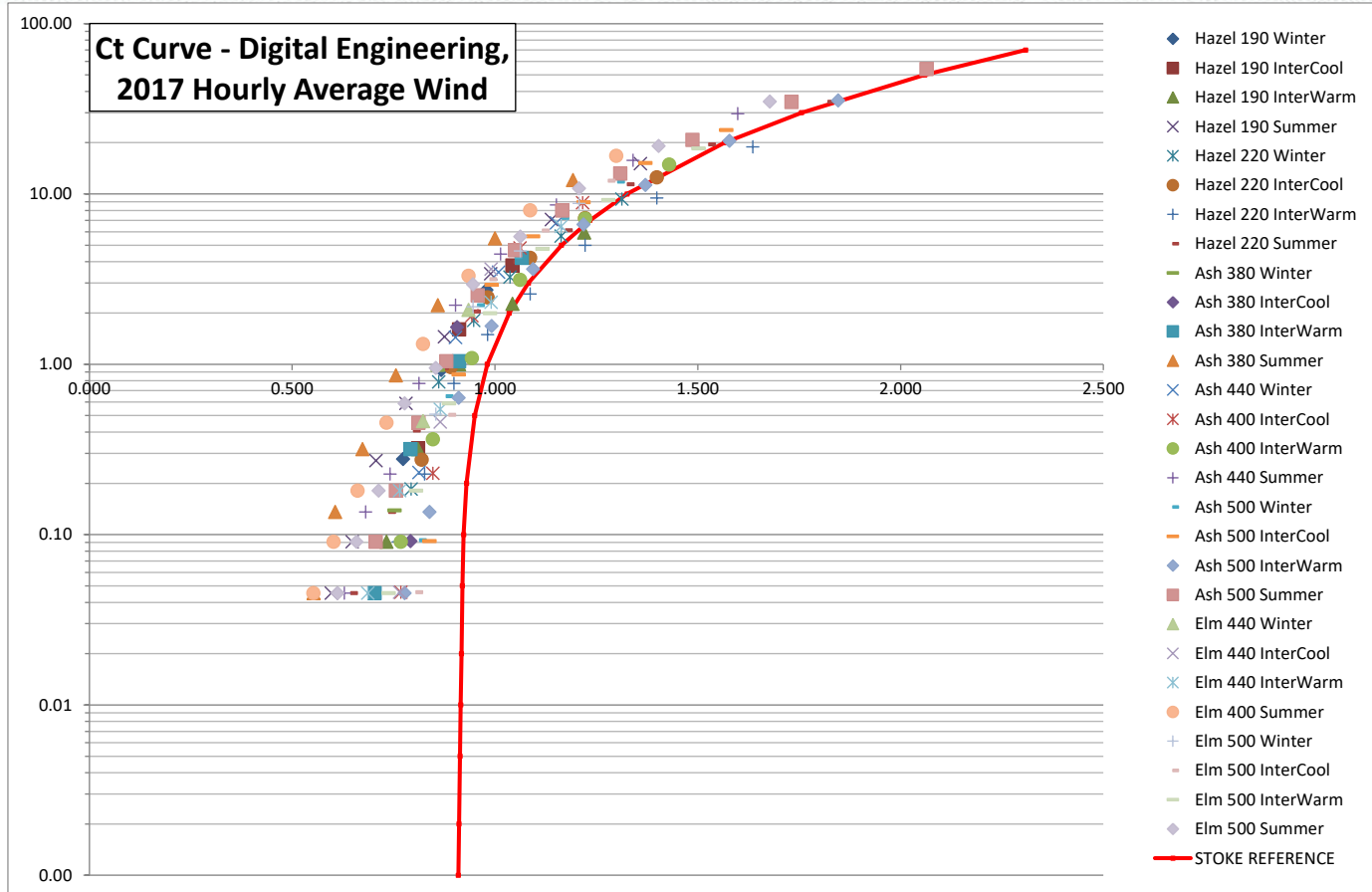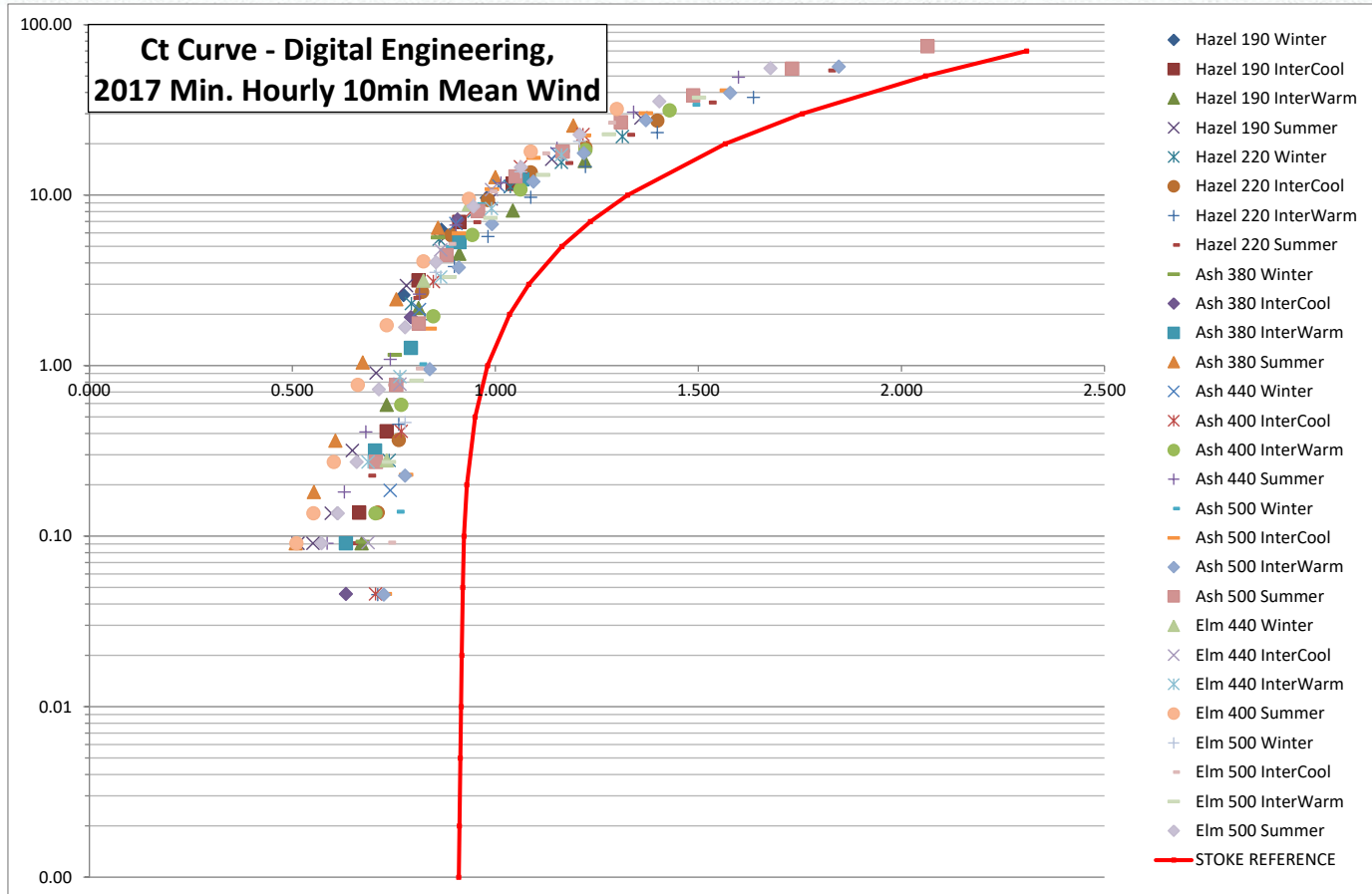
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Hindcast Datasets - Applicability

- Results of using hindcast datasets variable. Firm conclusions difficult to draw.

- Digital Engineering data gives low scatter but is highly conservative – hourly average winds, rather than minimum winds, give closest agreement.

- Met Office data gives higher scatter but best agreement vs temperatures calculated from logger data ("on-hour" 10min mean)

Application of Ratings - Building a Risk Model

- Ultimately, we use (and obey!) overhead line ratings in order to avoid electrical flashovers resulting from excessive sag

- The UK's regulations – ESQCRs – allow for an element of risk

  - Clearances must be maintained at a conductor's _likely_ maximum temperature

- What is an appropriate level of risk for flashover, and how does this determine the tolerable exceedence to be chosen in order to derive C_T.

Building a Risk Model – Flashover

- Flashover requires a combination of events:

  1. An infringement of design clearances – **P(Clear)**
     - Sufficient to result in breakdown of air insulation

  2. To a "limit case" obstacle – **P(Obstacle)**
     - Some obstacles fixed (buildings)
     - Some obstacles variable (vehicles, people)

  3. Under limit case voltage conditions – **P(Volts)**
     - Switching surge? Power frequency?
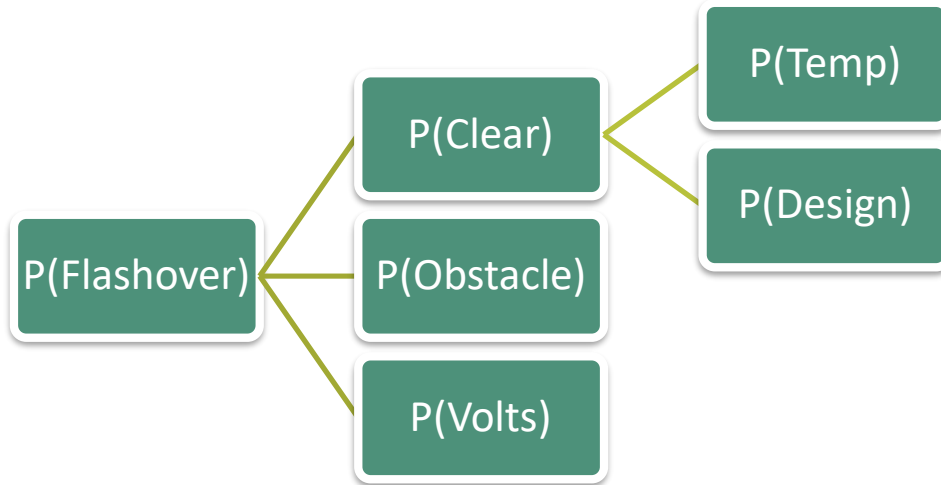
Building a Risk Model (1)
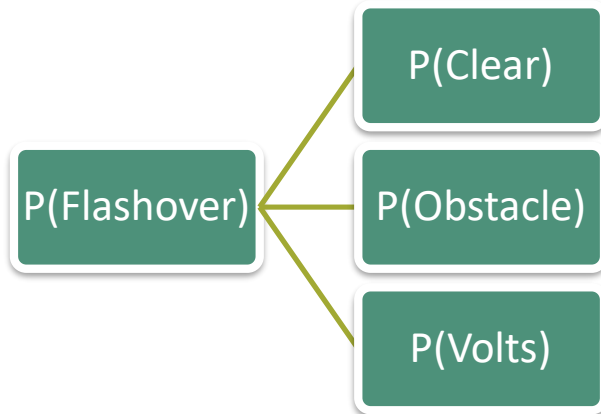
Building a Risk Model – Clearance

- A clearance infringement further requires:

    1. A conductor temperature excursion – **P(Temp)**

        - Greater than the line's design / profile temperature

    2. By a margin sufficient to overcome any "fat" in the line's design – **P(Design)**

        - Line geometry will often result in clearances greater than required by design standards

            – Structure height increments

   – Structure placement / span length limitations

Building a Risk Model (2)

Building a Risk Model – Temperature

- A temperature excursion further requires:

  1. A line (current) loading greater than the minimum "zero exceedence" rating – **P(Load)**

  2. While the prevailing weather conditions provide insufficient cooling – **P(Weather)**

- In this context P(Weather) is the "Exceedence"

Building a Risk Model (3)
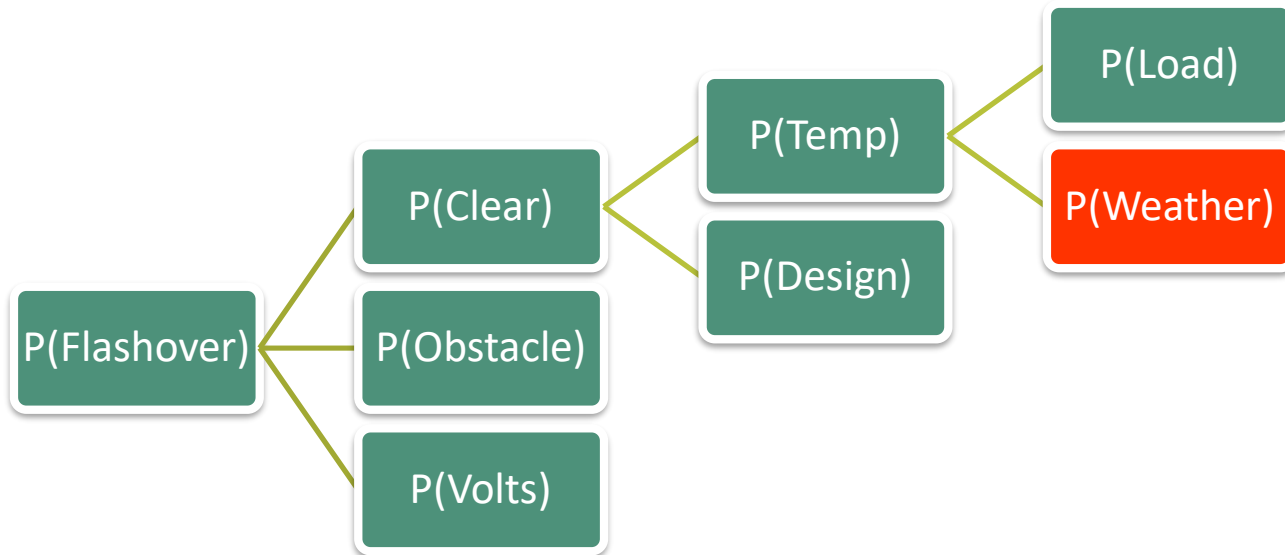
Note - Flexible Networks

- Originally aimed to have new P27 incorporate a "standard" load duration curve and, therefore, a standard value of P(Load)

- Alternative connection schemes and renewables now mean that this is no longer considered appropriate

- Software tool will, however, allow DNOs to consider load scenarios themselves

- P27 ratings will be based on conservative values

Application of Ratings – Enhanced Application

- Impossible for one document, P27, to cover all possible rating scenarios

- Software tool will allow DNOs (DSOs??) to assess risk levels for any load / weather scenarios desired

Custom Ratings - Opportunities

- With better information, favourable correlations could be exploited, particularly wind farm connections

  - High wind = High output = High rating

- Unfavourable correlations could be explored in more depth, particularly for PV connections

  - High solar = High output = Low? Not-so-low? rating

Next Steps

- Closedown report due end of September 2018 with final conclusions and recommendations.

  - Closedown Report to act as replacement / updated ACE104

  - Recommendations will form basis for updated P27 in conjunction with software

- Full datasets will be available for further study

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