Celsius

Business as Usual Implementation and Engineering Recommendations

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Welcome

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Agenda

- Welcome and introductions
- Intro to Celsius
- A BAU process that incorporates Celsius
- BAU implementation of Celsius
- Incorporation of learning into Engineering Recommendations
- Next steps in the project

Key take-aways

Through this workshop, we want you to take away the following points:

Celsius has developed learning that **could be incorporated into BAU** asset management and planning

The **Celsius methods are valuable**, with a positive cost benefit analysis and relevance in today's networks as well as smarter and more connected networks of the future

The project has developed **tangible approaches and tools to enable BAU** implementation that could be applied across DNOs

The learning from Celsius could be **incorporated into Engineering Recommendations** i.e. to update P15.

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Who is on the call?

Lead and presenting:

- Julian Pardo - ENA
- Delroy Ainsworth - ENW
- Olivia Carpenter-Lomax – Ricardo
- Michael Kelly - Ricardo

Delegates:

- Geraldine Paterson – ENW
- Matt Kayes – ENW
- John Baker – SSE
- Mark Mitchinson – SSE
- Jie Dai – SSE
- Peter Lang – UKPN

Celsius Project

Introduction and context

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Celsius introduction

Funded by the **2015 Network Innovation Competition**

Project runs from **January 2016 to March 2020**

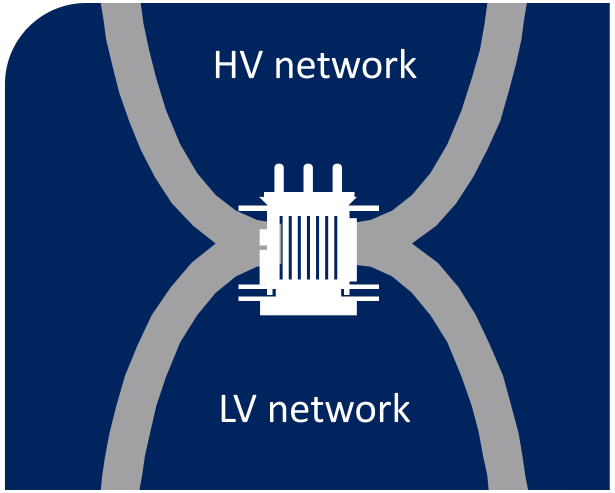
Total project cost: **£5.5m**

Estimated **benefit of £500m** over Great Britain up to 2050

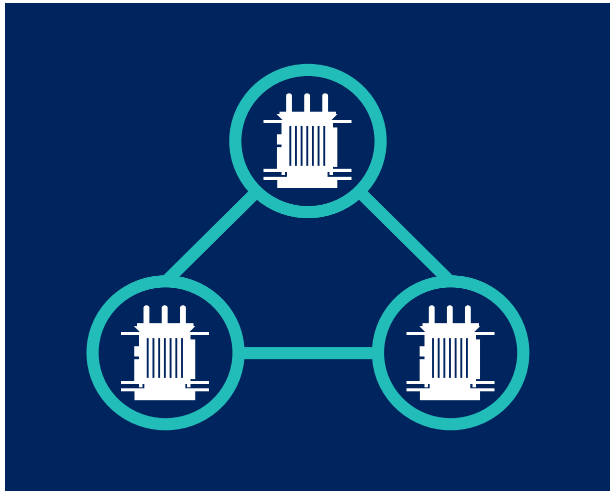
Project partners

Electricity North West	Ricardo	ASH	Impact Utilities	UK Power Networks
Lead partner, distribution network operator	Technical partner, focusing on trial design, analysis, deliverable development	Providing monitoring equipment for trials	Customer engagement partner	London and South East distribution network operator

Celsius



Celsius aims to increase capacity in distribution substations, enabling connection of low carbon technologies and reducing the need for costly substation reinforcement



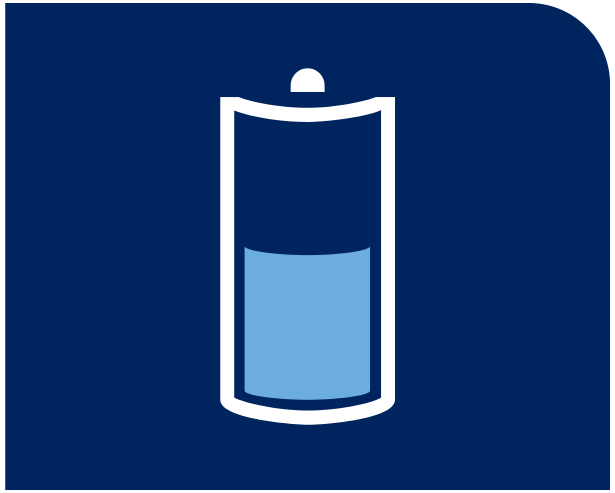
Assets have nominal thermal rating

Ratings $=$ ^{o}C

Ratings $\neq$ amps

Diverse range of environments

Small changes in environmental factors can result in very different actual ratings



Assumed thermal ratings can lead to capacity being under-utilised or unnecessary risk

Celsius methodology outline

2016 | 2017 | 2018 | 2019 | 2020

Phase 1: Monitoring trial

520 substations, representative of the whole substation population.
Data used to understand the impact of environmental factors on asset temperature and develop improved thermal ratings.

- Technology development and installation
- Monitoring trial
- Analysis

Phase 2: Cooling technology trial

Installing technologies in 100 sites.
Cost benefit analysis informed by monitoring before and after installation.

- Technology identification and installation
- Cooling technology trial
- Cost benefit analysis

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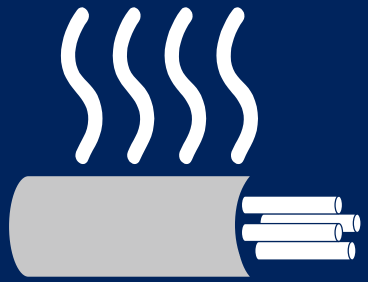
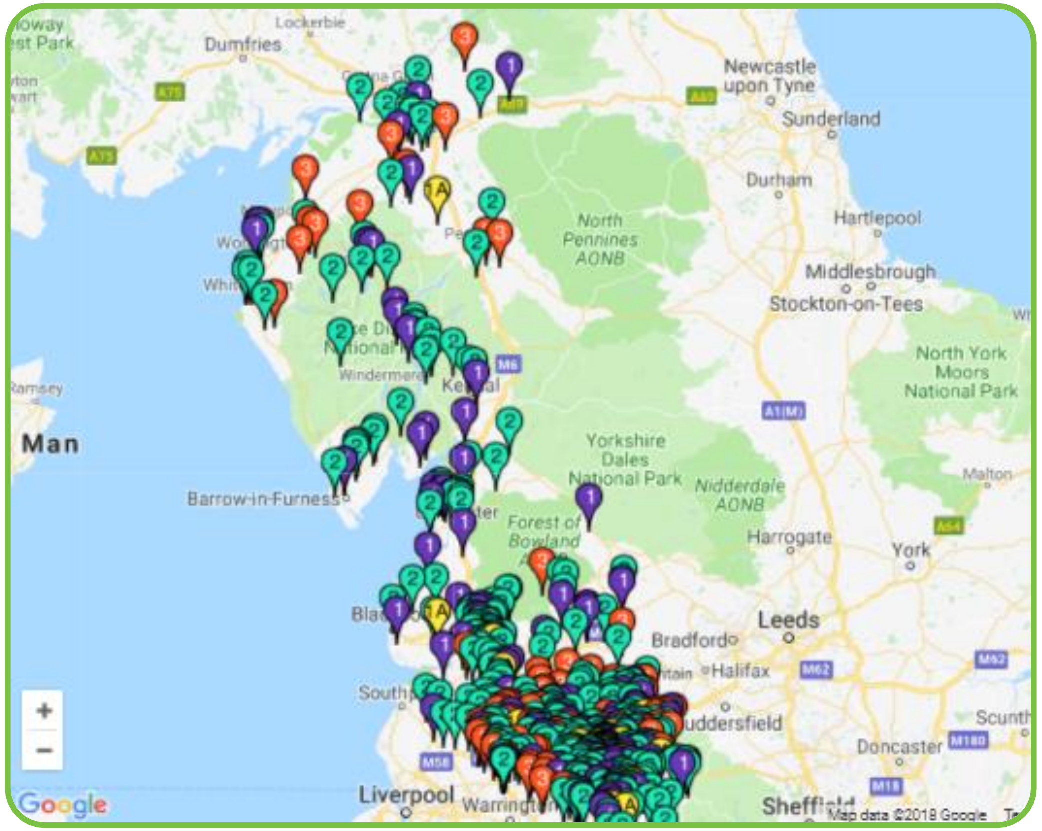
Cooling Technologies Examples

Active ventilation	Painting outdoor transformers	Improved passive ventilation	Cable backfill
			
Using fans to either drive cool air into or extract warm air from the substation. Two technologies tested in ~40 substations	White paint used to reflect solar heating of the asset Tested at 10 outdoor substations	Improved configurations supported by the Thermal Flow Study results. Trialled in ~50 substations.	Backfilling cable ducts with a material with beneficial thermal properties, to allow heat to escape from cables more effectively

Celsius project activity

Phase 1: Monitoring trial

Factor report, focused on transformer temperature, published in September 2018
(to be updated in February 2020)



Phase 2: Cooling technology

Cooling technology report produced in September 2019
(to be updated in February 2020)

Negative pressure ventilation
Installed at 20 sites

Positive pressure ventilation
Installed at 20 sites

Improving passive ventilation at substations
Installed at 41 sites

Painting outdoor transformers
Installed at 10 sites

Shading outdoor transformers
Installed at 5 sites

Improved cable backfill
Installed at 4 sites

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Celsius project key learning

Phase 1: Monitoring trial

A more informed rating can be derived for a transformer by using two temperature measurements and three phase power.

Most transformers have more capacity than their nominal ratings suggest for most of the time – their more informed ratings are on average ~30% higher than nominal.

There are factors that impact the operating temperature of a transformer. These include:

- Building environment
- Season
- External weather temperature
- Transformer age
- Harmonics

These factors interact; e.g. A transformer installed outside in winter might have ~20% higher rating, on average, than a transformer installed in a brick built substation in summer.

Even taken together, these factors cannot be used to derive the improved rating; the correlation is not strong enough to build a model without using measured data.

Phase 2: Cooling technology

Retrofit cooling technologies can be used to cool the transformer, and therefore release further capacity

Positive pressure ventilation

10% average improvement and possibly up to 25% capacity release.

Negative pressure ventilation

Highly variable performance, with capacity release up to 20%, but with some sites showing little or no improvement.

Improving passive ventilation at substations

A wide range of impacts, with 7% or more capacity release in some sites, but many others with no significant change.

Painting outdoor transformers

Some sites showed significant benefits, though not all sites saw improvement.

Shading outdoor transformers

Only limited data available due to loading issues. Data suggest that a small capacity release is possible in some sites.

Improved cable backfill

Not yet assessed

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Discussion and reflections

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Celsius BAU process

Suggested changes to the business as usual asset management process

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Approach to BAU process development

Gathering insight	Establishing today's process	Incorporating Celsius learning	Cost benefit analysis
• Including representation from BAU functions within ENW as much as possible • Including our UKPN partners to review from a different perspective	• Understanding today's process in as much detail as possible and relevant • Including what is actually done on the ground, practicalities and limitations	• Introducing elements into the process to incorporate Celsius learning • Aiming to provide maximum value from the learning, through practical and achievable changes	• Developing a cost benefit model to understand the value of the methods • This includes a GB-scale model for roll out

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Today’s process

Data collection, storage and reporting

Data stored in Ellipse:

- Nameplate data recorded
- Nominal rating is used in all circumstances
- Maximum Demand Indicators (MDI), spot temperatures, and condition (~ every 6 months)

Determine Asset Risk and Health Index (HI) using CNAIM model and Ellipse data

Trigger for intervention decision

Decision for intervention triggered by:

- Load growth (shown by MDI readings)
- Connection of additional load
- Network referral
- Asset risk score above threshold
- Asset failure
- At risk asset types
- NTR and diversion projects

Decision process for intervention

Decisions are made by the relevant team (asset management, capacity strategy and connections) by collecting and validating the relevant information. Data is collected to validate MDIs.

Intervention

Interventions include:

- Do nothing
- Reconfiguration of network
- Transformer replacement / additional substation
- Other approaches: refurbishment, maintenance, forced cooling

Celsius process

Data collection, storage and reporting

Data stored in Ellipse:

- Nameplate data recorded
- Nominal rating is used in all circumstances
- Maximum Demand Indicators (MDI), spot temperatures, and condition (~ every 6 months)

Determine Asset Risk and Health Index (HI) using CNAIM model and Ellipse data

Sites with Celsius monitoring:

- Celsius rating is used, nominal rating is recorded for reference
- Demand and temperature data comes from Celsius monitoring data
- CNAIM will use more informed rating and more accurate loading and temperature data

Trigger for intervention decision

Decision for intervention triggered by:

- Load growth (shown by MDI readings)
- Connection of additional load
- Network referral
- Asset risk score above threshold
- Asset failure
- At risk asset types
- NTR and diversion projects

Sites with Celsius monitoring:

- Celsius monitoring notification

Decision process for intervention

Determine if the site should be a Celsius site (if not already)

If the issue is temperature / load related and not time limited, and there is a positive CBA

YES: Celsius monitoring installed, more informed rating calculated Celsius data to support identification of further intervention

NO: Decisions made by comparing business cases of technically appropriate solutions. Data is collected to validate MDIs.

Intervention

Interventions include:

- Loading to Celsius rating
- Retrofit cooling solution
- Reconfiguration of network
- Transformer replacement / additional substation
- Other approaches: refurbishment, maintenance, forced cooling

- Do nothing
- Reconfiguration of network
- Transformer replacement / additional substation
- Other approaches: refurbishment, maintenance, forced cooling

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Benefits

Benefit	Description
Direct capacity release from the more informed rating	The more informed rating will be higher than the nominal nameplate rating in the majority of cases. This will mean that additional load can be supported before intervention is required.
More informed asset data in databases	The rating, demand and temperature data for Celsius sites will be more accurate, allowing for more accurate inputs into the CNAIM model, leading to more informed investment decisions.
Demand and temperature data available	The more detailed, half hourly data available for Celsius sites can be used to inform asset management, planning and connections decisions for that substation and surrounding network.
Ongoing reassurance from asset temperature notifications	Notifications can be generated from the data and sent to key personnel in ENWL. They will aim to reduce risk that Celsius sites overheat or fail, while enabling operation closer to the safety margins.
Possible reduction in frequency of site visits	It may be possible to reduce the frequency of visits to Celsius sites due to the increased visibility. It is recommended that this is carefully considered once the Celsius process is established.
Fast response to changing system demands	Celsius methods can be used to buy time in a world where demand for network intervention is increasing and there may be resource issues in meeting this requirement. Celsius enables smarter decision making by providing data and actionable information on Celsius sites.
Additional benefits from monitoring data	Increased network visibility can have significant advantages, and the data can be used for other insights. For example, additional insight into the current, voltage, and imbalance of the load on the network. It is recommended that additional studies are established to determine these opportunities.

CBA Results

Roll out scale	Benefits of Celsius methods over traditional up to 2050 (£m)
Electricity North West	31
GB	395

Methodology / Assumptions

- **The context** assumes an overloaded substation with a growing load over time.
- **Base case assumes** that once a substation is overloaded, the overloaded is validated, low cost options are sought, and if required, the transformer is replaced by a larger one. If the transformer is already 1000kVA, then an additional substation is installed.
- **Celsius case assumes** that an overloaded substation has Celsius monitoring installed, and it is assume that a higher more informed rating is found. If that is exceeded, then cooling is considered, before finally the traditional reinforcement process is used.
- **ENW scale** is defined by the Future Capacity Headroom (FCH) model, which provides estimates of the load growth of the substations that will become overloaded up to 2032. It is assumed that the trends remain similar beyond that date.
- **The GB scale** was defined by increasing the numbers proportionally according to the number of substations in GB compared to ENW.
- **Sensitivity analysis** was carried out into the impact of key assumptions in the modelling. These results indicate that the scale of these benefits may vary with the potential variance in assumptions (model results ranged from 365m to 502m).

Discussion and reflections

Further Work

Further areas of improvement:

- **Ongoing Celsius rating refinement:** As data is collected for a wider range of heavily loaded sites, the understanding of Celsius rating can be updated and developed to include this new learning. Note that there are limitations to the methods developed in Celsius due to the practicalities of data collection and analysis, meaning that the method has been developed using only a subset of representative examples.
- **Ongoing improvement to estimating cooling technology benefits:** As more examples of cooling technologies are installed, the learning about the benefits and limitations can be added to those of the project, and this can be used to refine the cost benefit assessments for selecting and designing interventions.
- **Addition of alternative interventions:** As further innovative technologies, including additional cooling technologies as well as other capacity release methods, are implemented into BAU, they can be incorporated into the Celsius BAU process. In many cases, the availability of Celsius data for the sites with monitoring would be of benefit in selecting and designing the most appropriate intervention, including the as yet unknown further innovative technologies.

Potential for further development of these methods:

- **Dynamic Rating:** The Celsius methods are a positive step towards developing usable dynamic rating approaches for DNOs. The potential of dynamic rating for transformers in GB distribution systems can be significant, particularly when coupled with the ability to actively manage energy flows in the system, e.g. with DSR, dynamic generation and storage. A real time or dynamic rating would be of significant added value to these techniques by providing additional capacity that can be leveraged as needed, without the need to reinforce equipment.
- **System Visibility, Forecasting and Modelling:** Gathering data at a distribution substation level can be used to produce wider value, including increasing the accuracy of operational and planning models, and providing further information needed to support connections requests.
- **Investigation of other Data Aspects:** Further insight could be gained from the monitoring gathered both during this project and during BAU implementation of the methods, for example, to understand the practical implications of phase unbalance and harmonics.

BAU implementation of Celsius

Thinking through implementation and implications

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Practicalities of implementing Celsius into BAU

Engaging personnel	Developing key tools and analysis	Practical aspects
Senior leadership BAU function personnel	BAU Rating and intervention selection tool	Data integration Alteration of reporting practices Implications beyond the process defined

BAU tool introduction

The Celsius project has developed a tool with two parts:

Celsius Intervention Tool

- Allows the user to input substation information
- Returns details about potentially relevant Celsius interventions, including the likely cost and capacity release.

The Celsius Rating Tool

- Allows the user to determine a more informed rating, or 'Celsius Rating' from input data
- Requires half hourly measurement data and site information.
- If only limited data is available, then the results are less reliable.

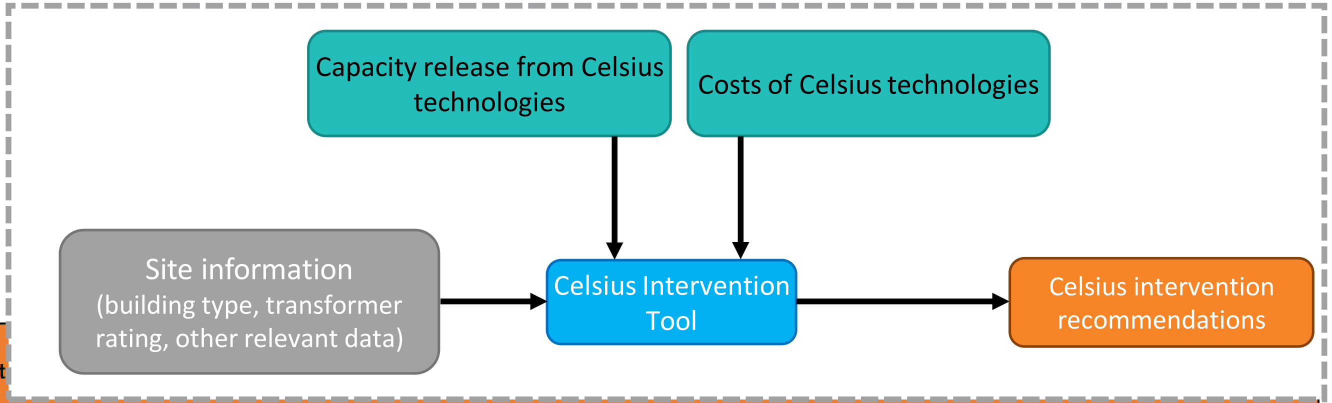
The aim is to support implementation into BAU by allowing users to investigate the solutions. This tool will be published with a User Guide on the Celsius website.

Celsius BAU tool: Celsius Intervention Recommendations

This tool provides data on relevant substation interventions that may release additional capacity if needed.
The substation information should be selected from the drop-down menus provided. Where options are not available in the drop-down lists, results cannot be provided as there is not sufficient trial data. The interventions, along with relevant cost, capacity release, and practical information will appear in the orange table.

Input site information

Building Type	Nominal Rating kVA	Is the substation exposed to direct sunlight?
Stone/Brick	750	No



Potential Celsius Interventions

Options	Predicted Capacity Release %	kVA	Mean Capacity Release across successful Celsius trials	Predict	
Monitoring + Celsius Rating	-5% - 50%	-37.5kVA - 375kVA	25% Based on 56 trials sites	£800 - £1000	Monitoring will include three phase power (voltage and current), transformer surface temperature at the top oil level, and substation ambient temperature. The Celsius rating is calculated from analysis of the relationship between transformer load and temperature. Monitoring is performed on an ongoing basis to provide risk mitigation. Note: substations with two transformers will require additional monitoring, with costs of ~£650.
Monitoring + Celsius Rating + Passive Ventilation	-3% - 8%	-22.5kVA - 60kVA	Additional 3% above Celsius rating alone. Based on 19 trial sites.	£2,300 - £4,000	Configuration of vents to improve passive ventilation. Benefit will depend on the configuration of the existing substation and the effectiveness of existing ventilation arrangements. Note: requires access and authority to alter the fabric of the building to alter the passive ventilation arrangements.
Monitoring + Celsius Rating		45kVA -	Additional 11% above		Installation of fans and configuration of vents to encourage forced ventilation. Benefit will be dependent on the configuration of the existing substation, but there is strong trial evidence that

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The Celsius Rating Tool

Celsius Celsius BAU tool: Celsius Rating

This model calculates a more informed rating, here called a 'Celsius Rating', from user input data, including monitored data

This model requires measured surface temperature, ambient temperature and load data (three phase current and voltage
additional substation information should be selected from the drop-down menus provided. Where options are not availa

The output is provided in the orange table below. This includes a Celsius Rating and a capacity release, both provided in k
insufficient data or data of not a high enough quality.

Input site information

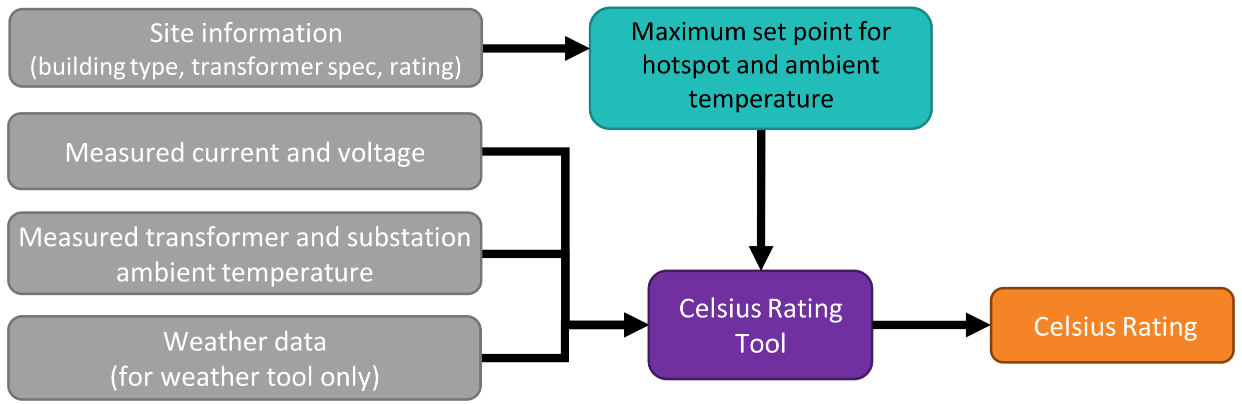
Transformer Specification	Building Type	Nominal Rating kVA
T1	Stone/Brick	800

Input measurement data - At least two weeks of half hourly data. Paste as values to keep formatting. Do

Measurement Time	Surface Temp	Ambient Temp	RMS Voltage Phase 1	RMS Voltage Ph					
02/04/2018 00:00	22.5625	15.6875	242.375						.13
02/04/2018 00:30	22.375	15.5625	242.125						.13
02/04/2018 01:00	22.25	15.5	242						.13
02/04/2018 01:30	22.0625	15.375	242						.13
02/04/2018 02:00	21.875	15.25	241.625						.14
02/04/2018 02:30	21.6875	15.0625	241.625						.14
02/04/2018 03:00	21.5625	15	241.625						.14
02/04/2018 03:30	21.5	14.9375	241.875						.15
02/04/2018 04:00	21.125	14.8125	241.625	246.625	245	194.375	138.75	137.25	0.14
02/04/2018 04:30	20.75	14.5625	241.25	246.125	244.5	179.375	139.25	144.75	0.14
02/04/2018 05:00	20.6875	14.375	240.875	245.625	244.125	171.375	139.5	141.375	0.14
02/04/2018 05:30	20.3125	14.25	240.125	244.875	243.625	177.625	141.125	135.25	0.14
02/04/2018 06:00	20.625	14.125	240.5	245.5	244.125	222.5	169.125	169.875	0.17
02/04/2018 06:30	20.5625	14.1875	238.875	244.375	243.125	301.5	213.875	209.375	0.22
02/04/2018 07:00	20.5625	14.0625	238.25	243.75	242.625	290.25	237	217	0.22
02/04/2018 07:30	20.375	14	238.875	244.25	243	284.5	244	225.125	0.23
02/04/2018 08:00	20.5625	13.9375	239.375	244.625	243.375	357.25	274.25	337.25	0.29
018 08:30	20.5	13.875	238.625	243.875	242.625	411	327	401.25	0.34
018 09:00	20.875	13.875	237.5	242.75	241.75	489	396.25	454	0.40
18 09:30	21.75	14	237	242.125	241	613	479	609	0.51
2018 10:00	22.5	14.0625	236.875	241.875	240.625	616	479	617.5	0.51

Note: it is expected that the calculation of Celsius rating is automated as part of the data acquisition / SCADA integration / asset database integration of the Celsius methods.

Celsius rating needs to be calculated based on ongoing monitoring, but this tool can be used to give an indication for 2 weeks of data or more.



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Other practical implications

Technical set-up

- Procurement of monitoring and cooling equipment
- Data management and comms
- Integration into existing SCADA / asset databases

Development of and training in new / altered procedures

- Intervention selection from Celsius as well as traditional techniques
- Installation / maintenance of monitoring and cooling equipment
- Use of more informed rating in planning, operation and connections

Points to note

- Noise consideration for active cooling technology is subjective.
- Site labelling (electronically and physically)
- Other equipment or settings may need to be changed to release network capacity (seen as unlikely)

Discussion and reflections

Engineering Recommendations

Incorporating learning from Celsius

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Status of P15

- P15 status is **‘no longer maintained’** and is available to all ENA members.
- Very old documents were set to ‘no longer maintained’ to avoid a third parties using the document and believing it to reflect latest recommendations.
- Due to its status it **should be used for information purposes only**.

- Nothing has superseded P15 – but the intention was that a revision/or new document would commence on completion of the Celsius project.
- 2021 is the best estimate of when this may happen.

Note: no amendments are recommended to P17 for the following reasons:

- The data and analysis from the cables trials are not conclusive
- P17 focuses on MV cables

Discussion and reflections

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Our suggested changes to P15

Changes within text

- Add in influencers to transformer temperature (i.e. building tyre, ventilation arrangements, ambient temperature, weather conditions)
- Mention option of calculating hotspot temperature based on external temperature measurements

New Appendix explaining the Celsius methods

- Calculation of hotspot
- Calculation of the more informed rating
- Worked examples
- Detail of limitation of these calculations and the ongoing further refinement to be done.

Discussion and reflections

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Next Steps and Wrap Up

Next steps in the Celsius project and BAU implementation

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Next Steps for ENW and the Celsius project

- **January:**
  - BAU tool and user guide
- **February:**
  - Updated reports for temperature factors, cooling technologies, CBA
- **March:**
  - Celsius Closedown Report
  - Produce ENW’s approach to managing thermal constraints at distribution substations and provide training for planners/operators on new techniques.
  - Submit Proposals for Changing ER P15 and ER P17 to ENFG

Discussion and reflections

QUESTIONS & ANSWERS

Please contact us if you have any questions or would like to arrange a one-to-one briefing about our innovation projects

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