Celsius Solutions: Cost Benefit Analysis and Buy Order

Cost benefit analysis and buy order for the techniques and solutions developed during the Celsius project, and being recommended to Business as Usual

Report for Electricity North West

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1 Introduction

1.1 Celsius Project Summary

The Celsius project was awarded funding under Ofgem's 2016 Network Innovation Competition (NIC). It is being led by Electricity North West (ENWL). Ricardo Energy & Environment are acting as key technical consultant project partners on this project. The project started in January 2016 and will be completed in March 2020.

The Celsius project has developed techniques and demonstrated solutions that can release capacity in existing ground mounted secondary transformers, thereby potentially delaying the need to reinforce as the load grows. These methods are limited to ground mounted transformers that have a nominal rating of 300kVA and above. This includes:

- **A methodology for determining a more informed transformer rating**, which takes into account substation environment and monitoring data. It is noted that the nameplate rating provided on a transformer is conservative, and that under many substation environments and loading conditions, a higher rating may be able to be adopted. This rating is limited by the operating temperature of the transformer, and a more informed rating can be determined by comparing operating temperature with the transformer load and estimating the actual load at which the maximum allowable operating temperature will be reached.
- **Cooling technologies and solutions**, which can be retrofitted into the substation or on the transformer to lower the operating temperature, and therefore release additional capacity.

The first phase of the Celsius project trials and analysis involved 520 secondary transformers. These trials developed the methodology for determining an improved rating for the transformers based on measured data and site information. This analysis was based on detailed data and information gathered and analysed through statistical methods. This analysis was reported in the 'Secondary Network Asset Temperature Behaviour Report', which was re-issued in March 2020. This phase concluded that it is possible to identify a more informed rating from site information and data, and that the capacity release from this varies widely between sites.

The second phase of the project and analysis involved installing retrofit cooling technologies into 101 of these trial sites, to assess their benefits and impact on the more informed rating. This analysis was reported in the 'Celsius Retrofit Cooling Report', which was re-issued in March 2020. This phase of the report concluded that the following technologies may be of benefit when installed into a substation:

- **Active ventilation of substations**: where air flow is increased though fans in order to cool the substation.
- **Improved passive ventilation of substations**: substations generally have established passive ventilation arrangements, but it may be possible to improve these arrangements, particularly if the existing arrangements are not optimal.

Other technologies and methods were trialled, including protection of outdoor transformers from solar gain, but the results of these trials were inconclusive. The project also investigated the thermal behaviour of pole mounted transformers and cables; however, these investigations did not result in any business as usual recommendations. This report is focused on ground mounted substations only.

Following this work, the learning from the two phases has been combined to form recommended updates to the business as usual network operations. Part of this is documented in the 'BAU Monitoring Solution Specification Report', delivered in September 2019, which covered the recommended process itself, and the requirements of the associated monitoring solution. This document provides the results of business case analysis for the implementation of Celsius techniques compared to traditional methods.

1.2 This Document

This document includes the following sections:

- **Section 2: Buy Order: Intervention Cost Assumptions** – A list of the various Celsius and traditional techniques, with associated costs and relative advantages and disadvantages.

- **Section 3: Cost Benefit Analysis**– Describes the methodology and results of the Cost Benefit Analysis (CBA) for the Celsius business as usual recommendations including the limitations, confidence and conclusions that can be drawn.

2 Buy Order: Intervention Cost Assumptions

The following table provides cost and benefit details for each Celsius technology, and equivalent traditional technology.

The costs information for the Celsius technologies is based on trial experience and information provided by suppliers. There is uncertainty in this cost due to the range of site characteristics, for example, substation shape and size, ease of providing any required supply points, and ease of making structural changes. For this reason, a range of costs is given in many cases. It is assumed that there is no notable increase in operational costs for ENWL as a result of utilising the technologies, as any minor maintenance will fall in line with usual substation inspection timescales. This has been supported by information gained from suppliers of the active cooling technologies and is part of the specification for monitoring solutions developed as part of this project. Capital costs assume that the Celsius technologies have been integrated into an established BAU process including communications, SCADA, training of personnel, and maintenance.

The traditional reinforcement approach includes replacing transformers with a larger capacity and building a new substation. The traditional options were selected with agreement from ENWL to reflect a likely approach to reinforcing a substation with increasing load. The costs have been supplied by ENWL. It is assumed that there is no notable increase in operational costs for ENWL.

Technology	Capital Cost	Capacity Release
Traditional: reinforcement to a 500kVA transformer	£17,408 Assumes no new plinth or generator is needed	59% - 67% Assuming existing transformer is between 300kVA and 315kVA
Traditional: reinforcement to a 800kVA transformer	£18,813 Assumes no new plinth or generator is needed	60% Assuming existing transformer is 500kVA
Traditional: reinforcement to a 1000kVA transformer	£18,813 Assumes no new plinth or generator is needed	25% to 33% Assuming existing transformer is between 750kVA and 800kVA
Traditional: installation of a new 800kVA substation	£75,000 Assumes near existing HV & LV network, land costs of £15k	80% Assuming existing transformer is 1000kVA (and remains in operation)
Celsius Intervention: monitoring and more informed rating	£800 to £1000 Includes equipment costs and installation	Depends on substation characteristics. Average release from trial: Stone/brick: 25% Glass reinforced plastic: 7% Part of larger building: 17% Fenced enclosure: 41%
Celsius Intervention: Active ventilation of substations	£3,500 to £4,000 Includes equipment costs, site preparation and installation	The most successful of the two technologies trialled released an additional ~14% of nominal rating on average above Celsius rating before installation, and in cases increased the Celsius rating by more than 30% of nominal rating.

Celsius Intervention: Improved passive ventilation of substations	Glass reinforced plastic: £500 - £700 Other sites: £800 - £3,000 Includes equipment costs and installation. Higher costs due to unusual site layouts and load bearing walls in shared buildings.	The trials showed that in some cases, 10% or more of nominal rating can be released when compared to the Celsius rating before installation. However, in other cases, little or no improvement is found. It is recommended that this method is only used where the existing arrangements are inadequate, or when active ventilation is not appropriate.

3 Cost Benefit Analysis

3.1 Methodology

The Cost Benefit Analysis (CBA) was carried out to determine the relative costs and benefits of the business as usual recommendations from Celsius compared to traditional methods.

The analysis focuses on meeting the load growth in the network, as this is the most straight-forward benefit case to model. The benefits to ENWL are in the form of reduced or delayed spending on network reinforcement. Benefits regarding reinforcement in response to specific connections requests are not included in the analysis as they are paid for, at least in part, by the customer who is connecting, and the timescale requirements for providing that connection offer means that it may not be possible to support connections requests using Celsius methods. Other benefits, such as efficiencies enabled by improved planning, maintenance and network visibility, are expected to have significant potential if they are leveraged. However, as these are less predictable, these are not included in the CBA analysis.

The CBA involves comparing two cases:

- **Base Case:** representative of the traditional reinforcement approach used for a transformer that is becoming overloaded
- **Celsius Case:** representative of the approach that would be possible with the Celsius methods

These cases are determined and compared for ENWL sites that are expected to be overloaded over the next 30 years, and the benefits are multiplied to extend to a GB scale. The sections below summarise the methodology that was used in order to carry out this CBA.

3.1.1 Base Case Definition

The base case assumptions have been defined and agreed with ENWL to be representative of the approach used in traditional reinforcement of a substation with load growth. It should be noted that it is not the aim that this process is exhaustive or representative of all cases, rather that it is a reasonable process with which to compare the Celsius case.

The assumed process once a substation is overloaded is as follows. As the CBA will be for 30 years of growth, multiple interventions are often needed for the same site. For example, a 300kVA transformer may be reinforced to a 500kVA transformer, and then continue to experience growth over the following years to eventually require another reinforcement intervention.

- **Validation:** The recorded load (usually recorded from the Maximum Demand Indicator, MDI, of the transformer) is validated using data logging to ensure that it is representative of actual load.
- **Investigation of reconfiguration options:** it may be possible to reconfigure the network to transfer some load from the overloaded transformer to a nearby transformer with spare capacity. This is a low-cost way of releasing capacity. In the business case we have modelled between 0% and 10% capacity being released in this way.

- **Traditional reinforcement – where the existing transformer is less than 1000kVA:** This includes replacing an existing transformer with a larger one, therefore providing further capacity without the need for additional substation infrastructure. The approach to transformer sizing is as follows:

Existing transformer	Assumed replacement within CBA	Assumed cost within CBA
50kVA, 100kVA, 200kVA	These transformers are not included in the analysis as the Celsius method is not validated for these transformer sizes.	
300kVA, 315kVA	500kVA	£17,408
500kVA	800kVA	£18,813
750kVA, 800kVA	1000kVA	£18,813

- **Traditional reinforcement – where the existing transformer is 1000kVA:** Transformers greater than 1000kVA are not commonly used at secondary substation level. Therefore, the transformer cannot be upgraded in the same way as the smaller transformers. In this case, it is assumed that it is possible to release capacity through reconfiguration (in addition to that described previously) and the reinforcement of an adjacent substation. It is assumed that an adjacent 500kVA transformer is replaced by a 1000kVA transformer, releasing 500kVA in capacity overall. The cost is assumed to be equal to a reinforcement to 1000kVA; £18,813.

- **Additional substation:** Where the load growth continues to grow and exceeds the capacity release from reconfiguration and reinforcement options, then an additional substation is installed. It is assumed that the new substation will be 800kVA, and that on installation the load will be shared between the new substation and the overloaded transformer. The cost of this new substation is assumed to be £75,000. If load continues to grow, then the additional transformer can be upgraded to 1000kVA, at a cost of £18,813.

3.1.2 Celsius Case Definition

The Celsius case is based on the BAU recommendations that have been developed by the Celsius project and are representative of the approach that could be used to support a substation with load growth.

The assumed process once a substation is overloaded is detailed below. As before, as the CBA will be for 30 years of growth, multiple interventions are often needed for the same site. Costs are assumed to be the average of those experienced in the trial.

- **Celsius monitoring and more informed rating:** Installation of monitoring will validate the load readings (as in the base case, these will most commonly be MDI readings) and will also allow a more informed rating to be calculated. The capacity released when a more informed rating is calculated varies with site characteristic. The CBA assumptions are based on the average capacity release from the trial of monitoring and more informed rating:
  - **Stone/brick:** 25% capacity release, at a cost of £974
  - **Glass reinforced plastic:** 7% capacity release, at a cost of £974
  - **Part of larger building:** 17% capacity release, at a cost of £974
  - **Fenced enclosure:** 41% capacity release, at a cost of £974
- **Cooling technology:** The Celsius project trialled a number of cooling technologies. The CBA assumes that the following technologies are used for each building type. These were selected as the most effective technologies at releasing capacity in the majority of situations, though it should be noted that the optimal solution and its effectiveness varies by site. The analysis assumes the capacity release to be the average capacity release from the successful implementations of each technology in the Celsius trials.

  - **Stone/brick:** Active cooling, releasing 20% capacity above monitoring and more informed rating alone, at a cost of £3,872
  - **Glass reinforced plastic:** Active cooling, releasing 23% above monitoring and more informed rating alone, at a cost of £3,872
  - **Part of larger building:** Improved passive ventilation, releasing 6% above monitoring and more informed rating alone, at a cost of £2,302
  - **Fenced enclosure:** No technology was selected
- **Traditional reinforcement:** Where the load exceeds the capacity release achieved through monitoring, improved rating and cooling, then it is assumed that the site is reinforced using the same traditional reinforcement approach as described in Section 3.1.1.

The model assumes that the Celsius methods are ready to deploy, and any necessary integration into incumbent IT and revision of existing business processes has been carried out.

3.1.3 Electricity North West roll out scale

The assumptions used to calculate the ENWL roll-out scale include:

- **Overloaded sites up to 2033:** The Future Capacity Headroom (FCH) model provides detail of the transformers that will be overloaded up until 2033 and their load growth over this time. This list was filtered for ground mounted sites with ratings of 300kVA, 315kVA, 500kVA, 750kVA, 800kVA, and 1000kVA, and for sites that are up to 150% utilised in the first year of modelling. Where sites had already reached 150% utilisation in the first year of modelling, it was assumed that traditional reinforcement was deployed as a short-term measure. This provided ~1,100 sites.
- **Load growth beyond 2033:** The load growth assumptions beyond 2033 was assumed to be 3.5% per year, which was calculated from the average load growth of the data between 2018 and 2033. Sensitivity analysis was carried out to investigate the sensitivity of the results to this assumption.
- **Sites becoming overloaded after 2033:** The FCH data was then used to estimate the number and profile of sites that become overloaded in the years after 2033 up until 2050. It was assumed that the pattern and profiles of these sites are the same as the data up until 2033. This added an additional ~1,400 sites.

The resultant model included ~2,500 sites.

3.1.4 GB roll out scale

In order to estimate the roll out scale over GB, the results for ENWL were multiplied proportionately to the number of ground mounted distribution transformers there are in GB compared to in ENWL. It is estimated that there are 220,000 ground mounted secondary transformers in GB, of which 17,000 are in the ENWL area.

3.1.5 Modelling methodology

The model is based on an NPV calculation up to 2050 using a discount rate of 3.5%. Results are in 2019 values.

3.2 Results

The CBA model results are shown in the table below:

Roll out scale	Benefits of Celsius methods over traditional up to 2050 (£m)
ENWL	30
GB	387

These results reflect the modelling at the 'default' assumptions, which assume a 3.5% load growth in the long term forecast for each site (the short term forecast for each site is provided by the FCH model as described in Section 3.1.3) and assume no capacity released through reconfiguration before reinforcement of transformers below 1000kVA. As described in Section 3.1.1, the default assumption includes some capacity release from reinforcement when considering an overloaded 1000kVA transformer, where it is assumed that reconfiguration and reinforcement of an adjacent substation can release capacity.

Sensitivity analysis was carried out into the impact of altering these assumptions in the modelling. The tables below show the results of this sensitivity analysis over GB scale:

Modelling assumptions: Long term load growth of transformers	Benefits of Celsius methods over traditional up to 2050 at GB scale (£m)
2%	323
3.5% (default assumption)	387
5%	474
The load growth assumption makes a significant difference to the benefits results. However, even at modest load growth of 2%, the Celsius methods still provide a significant benefit over time. The assumption of 3.5% is taken from the FCH model data up to 2033 for ENWL, and so is considered a reasonable assumption.	

Modelling assumptions: Capacity release from reconfiguration	Benefits of Celsius methods over traditional up to 2050 at GB scale (£m)
10% capacity release for all sites as they first become overloaded	362
No capacity release modelled for transformers less than 1000kVA (default assumption)	397
The reconfiguration capacity release assumptions have limited impact on the model results. As the potential for capacity release from reconfiguration will be site specific, and the impact on the results is limited, this is not included in the analysis.	

4 Conclusions

These results indicate the scale of benefit that the Celsius methods could achieve compared to traditional methods. It should be noted that the results do not include other innovative methods that are available, or will become available, to support management of load in distribution networks. It is intended that the Celsius methods should become part of the toolkit of methods that a Distribution Network Operator can use as the demands on the network change over time.

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