Celsius Cooling Data Collection Summary

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Report for Electricity North West

Customer:

Electricity North West

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1 Introduction

1.1 Celsius

The Celsius project was awarded funding under Ofgem's 2015 Network Innovation Competition (NIC). It is being led by Electricity North West (ENW). Ricardo Energy & Environment is the key technical consultant partners on this project.

The Celsius trials involve 2 phases:

- **Retrofit monitoring Trial:** This trial included 520 11kV/LV distribution substations and pole mounted transformers, each of which have been fitted with a central communications hub and up to 30 sensors measuring transformer power and asset and ambient temperatures. The monitoring equipment is being provided by Ash Wireless, and Ricardo has provided a data management system and detailed data analysis to understand the thermal behaviour of network equipment and determine methodologies to produce more informed thermal ratings.
- **Retrofit Cooling Technology Trial:** Six retrofit approaches have been identified that could be used to manage heat at distribution substations. These technologies have been installed at 100 sites, and monitoring has continued at these sites to collect data that will be used to determine the benefits of the technologies.

The app and data management system was developed from early 2016, and the initial implementation was developed over the equipment installation period. In May 2017, a document was delivered that reported on the collection and management of Celsius data (Celsius Data Summary May 2017). A further document (Celsius Data Summary Feb 2018) was subsequently delivered to report on the continued data collection processes and the lessons learned.

The Celsius trials are now at the Retrofit Cooling stage, and monitoring has been installed alongside the retrofit cooling technologies to support assessment.

The following technologies have been selected for demonstration:

- **Directed forced ventilation:** Installed at 20 sites (provided by Ekkosense).
- **Positive pressure ventilation:** Installed at 20 sites (provided by Passcomm).
- **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:** To be installed at 4 sites (Note: as of March 2019, these sites have not yet been installed due to delays in monitoring trial).

1.2 Purpose of this document

The purpose of this document is to report on the changes made to the data handling system to support and accommodate the Retrofit Cooling Technology Trial. This includes:

- Update of data collection and back end data management system.
- Changes to data monitoring approach to support Retrofit Cooling Technology Trial.
- Documentation of the issues encountered, and solutions developed.

2 Monitoring and data solution overview

This section summarises the monitoring and data solution used for the Celsius project.

2.1 K^{e}LVN equipment

Celsius uses K^{e}LVN monitoring equipment, provided by Ash Wireless, to provide substation data. Included in the suite installed in a substation is:

- **Single temperature sensors**, which measure a single asset or environment temperature,
- **Hex unit**, which can connect up to 6 sensors. When voltage and current sensors are connected in the correct configuration, the Hex unit will calculate complex power from the data. The sensors that can be connected include:
    - **Voltage sensor**
    - **Current sensor**
    - **Temperature sensor**
- **Internal transformer temperature monitoring**, which can also be connected through a Hex unit, and measures the temperature of the oil within a transformer (selected sites only).

This temperature and power monitoring equipment communicates half hourly readings (Temperature readings are instantaneous every half hour, while power readings are root mean square over a few seconds taken every half hour). to a central Hub installed within the substation. Data is transmitted from the Hubs, once per day over the mobile network – the data is sent in four groups, each containing 6 hours' worth of data for that substation. The Hub can receive commands for a short period once a day when it connects to the back end.

2.2 Data management system

The data management system receives the data from each of the Hubs. It then stores and processes the data and provides visualisation and enables downloading for further analysis.

When monitoring data is received by the data management system, the following processes are performed:

- Validation of the incoming data packet using Hub ID and token, ignoring all other incoming data,
- Verification of Hub against stored sensor metadata,
- Population of Raw database, with all received data (i.e. whatever sensor data is present),
- Pass back to the Hub any relevant commands from the commands queue, for example to re-send previous data or measure detailed harmonics.

Raw data is analysed and checked for validity and processed. This includes rounding the timestamps to the nearest half-hour in order to support validation. After processing, the data is stored. Importantly, both raw and processed data are retained for diagnostic and troubleshooting purposes.

2.3 Installation Application

The installation application supports collection of site data and images, and the installation of monitoring equipment. The process for installation is:

1. The site is selected from a pre-populated list,
2. Critical information about that site is checked and collected,
3. The application presents the required installation positions,
4. As the sensors are installed, the barcode on each sensor is scanned and associated to their position,
5. The app displays initial measured values for each position, so the functioning of the equipment can be checked before the site is signed off.

2.4 Web Interface Functionality

This section summarises the functionality of the data management system and web interface. This includes the following functionality:

- **System Health Dashboard** – provides detailed information about the installed sites, including completeness of data, photos, and alert generation and tracking. The sites summary page includes visual indications of equipment communications connectivity and data completeness. A system health summary screen includes a map of the installed sites with filters for monitoring type, status, and issues, and summary of alerts data at a particular instant in time. There is a more detailed site screen which shows data completeness indicator bars for each sensor position. It also includes a map of the site location, a list of site alerts, and the site photographs that were taken during installation. An example of the system health screens is shown in figure 1 below.
- **Data Dashboard** – Provides visualisation of and access to monitoring data. This interface provides access to the data collected within Celsius. The data can be displayed in a table or graphs displayed within the web interface itself or can be downloaded in a CSV file for analysis locally. The data management system calculates additional data from that measured, including apparent power, power factor, and utilisation. Data can be filtered by a number of characteristics:
    - **Time** – any period can be selected from the start of the project to the present.
    - **Site** – any number of sites can be selected. To enable selection, the list of sites can be filtered for monitoring type or building type, or individual sites can be found by name or number using the search bar.
    - **Sensor position** – once data from one or more site is loaded, then this can be further filtered by sensor position, or by measurement type (for example, temperature, current or voltage).

  A quick 'latest data' download tool is also available, which enables download of the last day, week, 2 weeks or 4 weeks of data from a single site. This is a useful tool to download data quickly without having to set all of the filter options. Additionally, the 'snapshots' functionality produces a snapshot of Celsius temperature data monthly, so that it can be accessed by ENW and published for wider use.
- **Alerts** – Alerts are generated, either manually or automatically according to a set of rules, for example, to indicate data gaps, or measurements being reported that are outside of given threshold. Lists of alerts can be filtered based on the site, assigned person, status, and issue category. Detailed alert pages show the description of the alert, the history of comments and changes made, and display relevant graphs to indicate the issue. There are also links to site data and site health pages. Alerts can be assigned to an individual, commented and the status set to four options:
    - **Open** – this is the initial alert status set, and is used to indicate that the alert has not been resolved.
    - **In Progress** – indicates that someone is working on the issue.
    - **Closed** – indicates that the issue has been resolved.
    - **Accepted** – indicates that the issue has not been resolved, but a decision has been made that this issue should not be acted on any further, for example if the site has data gaps due to poor signal and nothing more can be done to improve it.
- **Admin** – The admin pages enable administration of the following aspects:
    - **Sites** – this screen lists all the sites within Celsius with key information such as location. Site details can be edited, and new sites added.
    - **Users** – Lists all of the users with access to the Celsius system and allows admin users to edit permissions, set passwords, and disable accounts. New users can also be added
    - **Roles** – Lists all of the available roles which set levels of permissions on the site. New roles can be added.
    - **Organisations** – Lists all of the organisations of the people who have access to the Celsius site and allows addition of more. This is useful as it allows users to be identified by organisation.

Users will have access to some or all of this functionality, depending on their permissions set in the Admin pages.

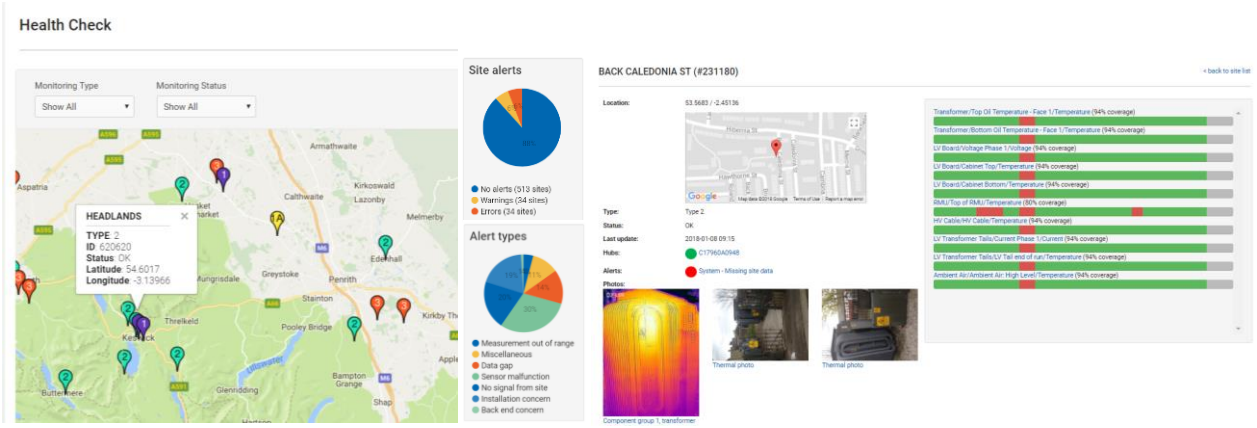

Figure 1: Screenshots from the Celsius Data Management System. Left: the site health check dashboard showing the location of sites and the alerts identified. Right: Data dashboard site detail, including data completeness for each sensor position, location, alerts identified, and photographs.

2.5 Data processing update

Since the delivery of the Celsius Data Summary Feb 2018, the following key changes have been made to the data management system:

- **Weather data:** Weather data from public sources has been added to the data management system for each site. This was achieved by determining the nearest weather data source to each site and retrieving appropriate data. The data available for each site is dependent on the monitoring equipment at the nearest public source weather station, but includes ambient temperature, precipitation, and humidity data.
- **Performance improvements:** As the data management system is managing large volumes of data, it requires significant processing to support the functionality of the visualisations. This was improved so that the site is more responsive.
- **Alarms:** The alerts system has been in operation for the majority of the trial. It was identified that it would be highly advantageous to implement a 'high temperature' alert, which will trigger if the reported temperature at any sensor position reaches certain temperatures (40 ^{o}C for a 'Warning' alert, 50^{o}C for a more serious 'Error' alert). The alert was then developed into an alarm, with an associated email notification to ensure that action can be taken quickly where necessary.
- **Changes to support the Retrofit Cooling Technology Trial:** This has included adding cooling technology categories into the site information and enabling the addition of cooling technology-specific monitoring positions. See Section 3 for description of this approach.

The data management system receives, stores, processes, and provides access to the Celsius data. The latest metrics are (as of March 2019):

- **About 2.8 million** inbound data packets handled.
- **Over 390 million** measurements stored.
- **Over 86,000** lines of code in the data management system.

The data collection for the Retrofit Monitoring Trial has ended. 100 of the monitoring trial sites have been chosen for Retrofit Cooling Technology installation, and data will continue to be gathered from these sites. The monitoring at the other sites is being uninstalled and the monitoring equipment decommissioned.

3 Celsius Cooling Trial Requirements

The Celsius project is now in the Retrofit Cooling Technology Trial phase. This phase installing cooling technologies at 100 of the Celsius trial sites. 96 of these sites have been installed, with the remaining four sites to be installed once the cable analysis is complete (this analysis has been delayed due to difficulty collecting the cable data from ENW existing sources).

In order to support the Retrofit Cooling Technology Trial, the following changes were needed in the data management system:

- **Cooling technology categories:** Adding categories for each cooling technology into the site information recorded in the installation app.
- **Cooling technology monitoring positions:** Enabling the addition of cooling technology-specific monitoring positions for use for certain types of monitoring solution.

These are described in more detail in the sections below.

3.1 Cooling technology categories

It was necessary to be able to identify cooling sites within the Celsius data management system, and to record which cooling technology was installed at each site. To this end, it was decided that an additional information field would be added to the installation application, to be edited as the cooling technology was being installed.

The categories used in the app are:

- **Solar shade:** This is only applicable to outdoor sites and aims to protect equipment from solar heating. It has been installed at 5 sites.
- **Reflective paint:** This is only applicable to outdoor sites; assets are painted a light colour to reflect solar radiation and protect equipment from solar heating. It has been installed at 10 sites.
- **Improved passive ventilation (GRP):** Painting GRP enclosures a light colour and installing improvements to the arrangement of passive vents to support passive ventilation particularly designed for stand-alone brick substations. This has been installed in 20 sites (11 with paint, 9 without).
- **Improved passive ventilation (Brick):** Improvements to the arrangement of passive vents to support passive ventilation, particularly designed for stand-alone brick substations. This has been installed in 19 sites.
- **Improved passive ventilation (Non-standard):** Improvements to the arrangement of passive vents to support passive ventilation, with a focus on non-standard substations such as those that are part of a larger building. This has been installed in 2 sites.
- **Forced ventilation (positive):** Suited to indoor substations. Fans are used to push air in through a low vent, which then passes over the substation equipment and escapes through a high vent. This solution is provided by Passcomm and has been installed at 20 sites.
- **Forced ventilation (negative):** Suited to indoor substations. Fans and ducting are used to direct and pull air over the substation equipment and out through a high vent. Cool air is drawn in through low vents. This solution is provided by Ekkosense and has been installed at 20 sites.
- **Cable backfill:** This cooling technology has not been deployed yet. It will use advanced cable backfill materials which support the transfer of heat from the surface of the cable.

The image below shows an example of the app screen with the cooling technology categories selected.

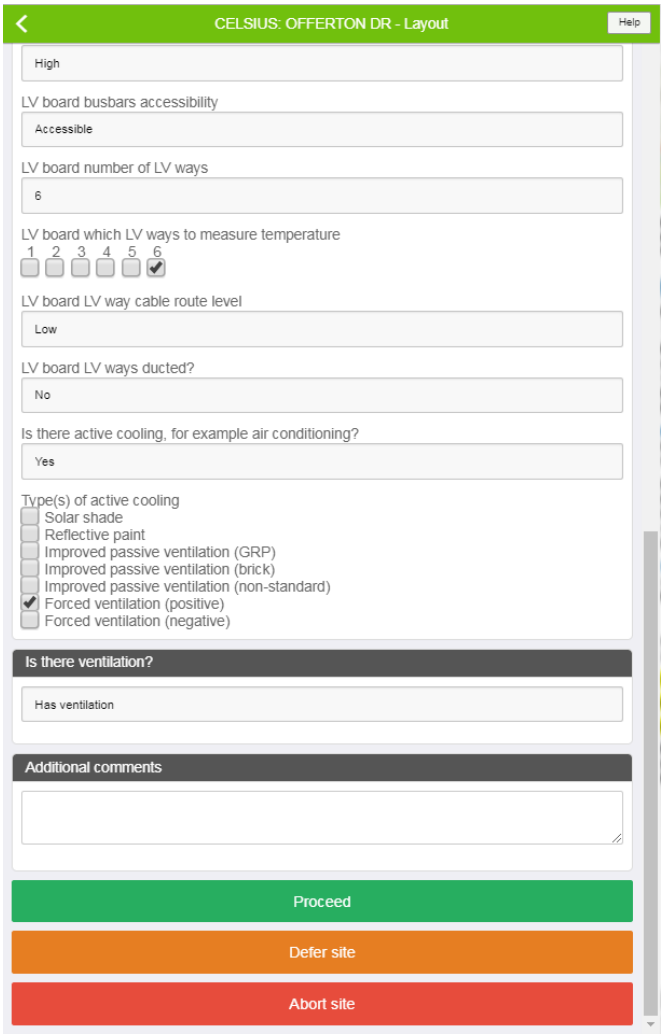

Figure 2: An example of the Celsius app site data screen with the retrofit cooling technology categories selected

3.2 Cooling Technology Monitoring Positions

The retrofit cooling technologies included in the trial fit into two categories:

- **Passive cooling technologies:** these are technologies which have no moving parts, and work through natural and simple means.
- **Active cooling technologies:** these are technologies with moving mechanical parts, which in the case of these trials, are fans which direct air though mechanical means.

For the sites where passive retrofit cooling technologies are deployed the existing sensor arrangement, as used in the retrofit monitoring trial, is sufficient for the cooling trial. However, sites where the two forced ventilation technologies are installed, additional sensors are needed to indicate the operation times and set points of the technology.

In order to achieve this, the following additional monitoring positions were defined and added to the Celsius installation app:

- **Ventilation setpoint temperature:** A temperature measured either by a single temperature sensor or a temperature measurement lead which can be used in conjunction with a Hex unit. This temperature is as close to the measured cooling technology set point as is possible to measure. The set point is used in certain modes of operation; when the set point temperature reaches a certain level, the cooling fan will switch on. When it drops to a certain level, it will turn off. This means that the fan can cool when needed, but otherwise is not using power unnecessarily.

- **Ventilation temperature other:** A temperature measured either by a single temperature sensor or a temperature measurement lead which can be used in conjunction with a Hex unit. This is another temperature position which can be used to indicate the fan unit temperature or another local temperature which would be useful for the analysis.
- **Ventilation current:** A current measured using a wedding ring CT which can be used to clamp around the power supply lead for active technologies to record the operation. The wedding ring CT is used in conjunction with a Hex unit.

These additional sensors were added to the installation application for sites that have one of the relevant cooling technology categories (Forced ventilation (positive) and Forced ventilation (negative)) selected. The overall configuration of sensors had to be carefully considered to ensure that it did not exceed the maximum configuration per site of 30 sensors, where up to three are Hex units. Beyond this number, data collection is impaired.

3.3 Recording of additional Cooling Technology Trial information

In order to support the analysis of the cooling technologies following the trial, it has been important to record key information, including:

- Installation dates and dates of any alterations.
- Issues noticed, and changes made as a result.
- Physical layout and characteristics of the installation.

These aspects have been recorded in a separate database, not included in the main data management system. This was due to the limited numbers and timescales of the trial, and the breadth of the types and format of the data to be recorded. While it would have been possible to extend the data management system, it was not considered a valuable addition to the project.

4 Issues and solutions

A number of issues with sensor and data management technology have occurred over the course of the project, and whilst they have been solved or mitigated, it is important to record these issues and the solutions deployed to ensure that learning is preserved. This section summarises the main issues experienced, focusing on the cooling technology trial, since the previous data update in February 2018.

4.1 Cooling technology installations and issues

While not strictly a data management issue, it is notable that there were issues in installing the cooling technologies which had the following impacts:

- Uncertainty in site selection, as some sites were found unsuitable for installation once the selection had been made. This was problematic as this meant that alternatives would need to be found, and there were many criteria which determined the suitability of sites to be included in the trial, including loading and temperature issues.
- Data gaps in early operation, due to the fact that sensors were not installed or commissioned correctly, or alterations onsite causing disruption of monitoring equipment.
- Malfunctions in operation of equipment, specifically the active technologies which had issues with programming and set points. This is taking some time to mitigate, which is a process being managed by ENW.

4.2 Data gaps in cooling technology data collection

Some data gaps are present across the cooling sites. This could be for the range of issues identified in previous reports (Celsius Data Summary May 2017 and Celsius Data Summary May Feb 2018) and is being mitigated through identification and replacement of cooling equipment where necessary.

4.3 Overheated substation

On the 4th March 2019, a high temperature alert was received for an active cooling site. As the ambient conditions were not conducive to high temperatures, this alert was passed on the ENW. It was discovered that the cooling fan had been turned off, and therefore was not performing its role. This was likely compounded by the fact that the installation of these technologies generally involves blocking of several vents in order to optimise the operation of the active cooling technology but means that if the technology itself is not working, the cooling is less effective.

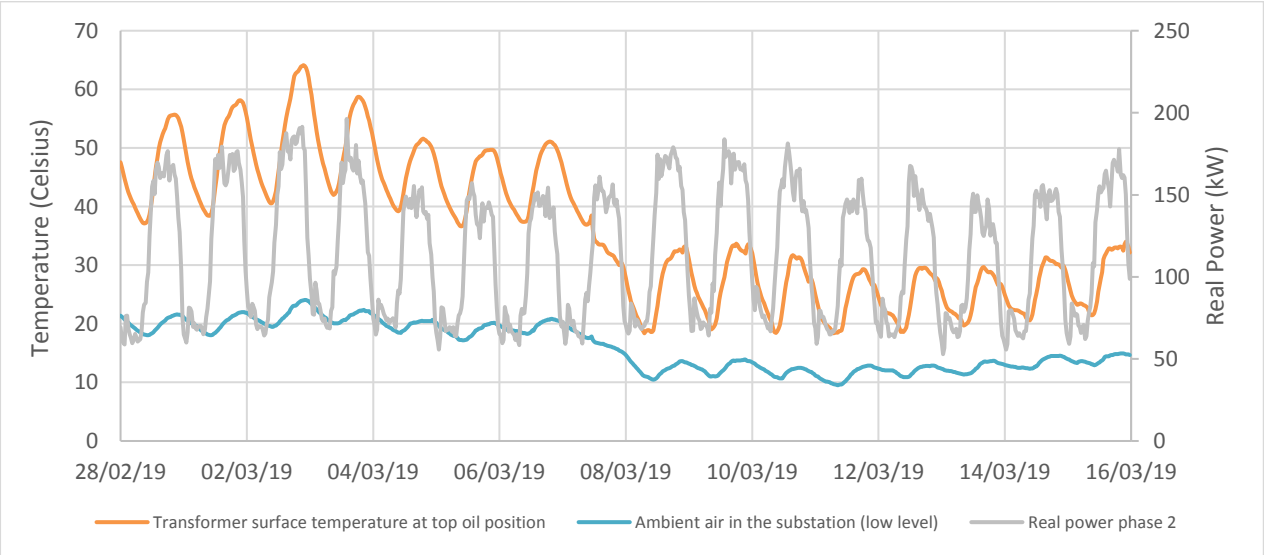

Figure 3: Graph showing the transformer temperature before and after the cooling technology was reinstated (07/03/2019), with phase 2 load and ambient temperatures shown for context.

The graph above shows the temperature at this site before and after the cooling technology was switched back on. The real power through phase 2 is shown for comparison (note, only phase 2 was monitored at this site). It can be seen that while the daily load cycle the site does not change significantly over the graphed period, the temperature of the transformer is drastically reduced after 7th March, when the cooling technology was reinstated.

This occurrence highlights the importance of high temperature alarms which allow action to be taken sooner, and access to remote data which is quickly accessible and allows situations to be assessed and addressed as appropriate. It also highlights that there is a potential downside in installing the active cooling technologies which compromise the passive cooling capability.

4.4 Data gap across all sites

A data gap across all sites is a symptom of a data management or received issue. This has occurred only a few times over the course of the project. One of the most significant was the data gap issue over Christmas 2018. It was identified that the data collection server had stopped functioning on the 21st December following some routine updates. The issue identification of the issue was delayed due to the Christmas holidays, meaning that not all of the data could be recovered. The data gap remains between 21/12/2018 and 07/01/2019.

5 Conclusion

The Celsius data management system receives, stores, processes, and provides access to the data from the substations. This has considerable functionality which has been developed and improved over the Celsius project, including the receiver, databases, automatic validation, web interface, and application. This has been developed further to support the Cooling Technology Trial.

Whilst it is not expected that additional functionality will be needed in all sites, continued assessment and monitoring of the alerts will support identification of issues, for example, in operation of cooling technologies which might otherwise risk substations reaching unreasonable temperatures.