Celsius Data Summary

Data Issues and Data Handling

Developed February 2018

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Report for Electricity North West

Customer:

Electricity North West

Contact:

Olivia Carpenter
Ricardo Energy & Environment
1, Frederick Sanger Road, Surrey Research Park, Guildford, GU2 7YD

t: +44 (0) 1483 547 013
e: olivia.carpenter@ricardo.com

Ricardo-AEA Ltd is certificated to ISO9001 and ISO14001

Author:

Olivia Carpenter

Approved By:

Sarah Carter, Cliff Walton

Date:

27 February 2018

Ricardo Energy & Environment reference:

Ref: ED62006- Issue Number 1

Table of contents

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 project partners on this project.

The Celsius trials involve 520 11kV/LV distribution substations and pole mounted transformers, each of which have been fitted with at least one 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 is described in a series of separate documents.

As part of the project, Ricardo has provided a mobile application which supports the installation of the monitoring equipment and enables recording of key installation and site data, and a data management system which receives data remotely from the monitoring equipment, processes, stores, and provides data access.

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). The functionality of the system has been developed and enhanced in many ways in the subsequent period.

The data is being used to develop detailed insight into the thermal behaviour of substation assets and environments. This is reported in another deliverable.

The next stage of Celsius is a trial of retrofit cooling technologies in 100 of the Celsius trial sites. There will be additional monitoring and data associated with some of these technologies, requiring minor feature changes to the installation app and data management system.

1.2 Purpose of this document

The purpose of this document is to provide an updated report on the collection and management of data for the Celsius trial as at February 2018. This includes:

- Update of data collection and back end data management system
- Documentation of the issues encountered and solutions developed
- Indication of the additional features needed to support the Celsius cooling trial

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 half hourly root mean square over a few seconds). 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 that for installation is:

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

3 Data processing update

The data management system receives, stores, processes, and provides access to the Celsius data. The latest metrics are (as of early 2018):

- **Over 750,000** inbound requests handled
- **About 130 million** measurements stored
- **Over 86,000** lines of code in the data management system

All of the Celsius sites have monitors installed, these will remain in place until the end of the monitoring trial, and the cooling sites will then be monitored for a further year. Therefore, the amount of data handled by this system will continue to grow substantially.

4 Web Interface Functionality

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

- **System Health Dashboard** – provides detailed information about the installed sites, including completeness of data, photos, and alert generation and tracking.
- **Data Dashboard** - Provides visualisation of and access to monitoring data
- **Commissioning Applications** – supports the collection of site data and the installation of sensors

- **Admin** – Enables management of users and sites, and allows some trouble shooting functionality.

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

4.1 System Health Dashboard

4.1.1 System Health Summary Screen

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. This is shown below:
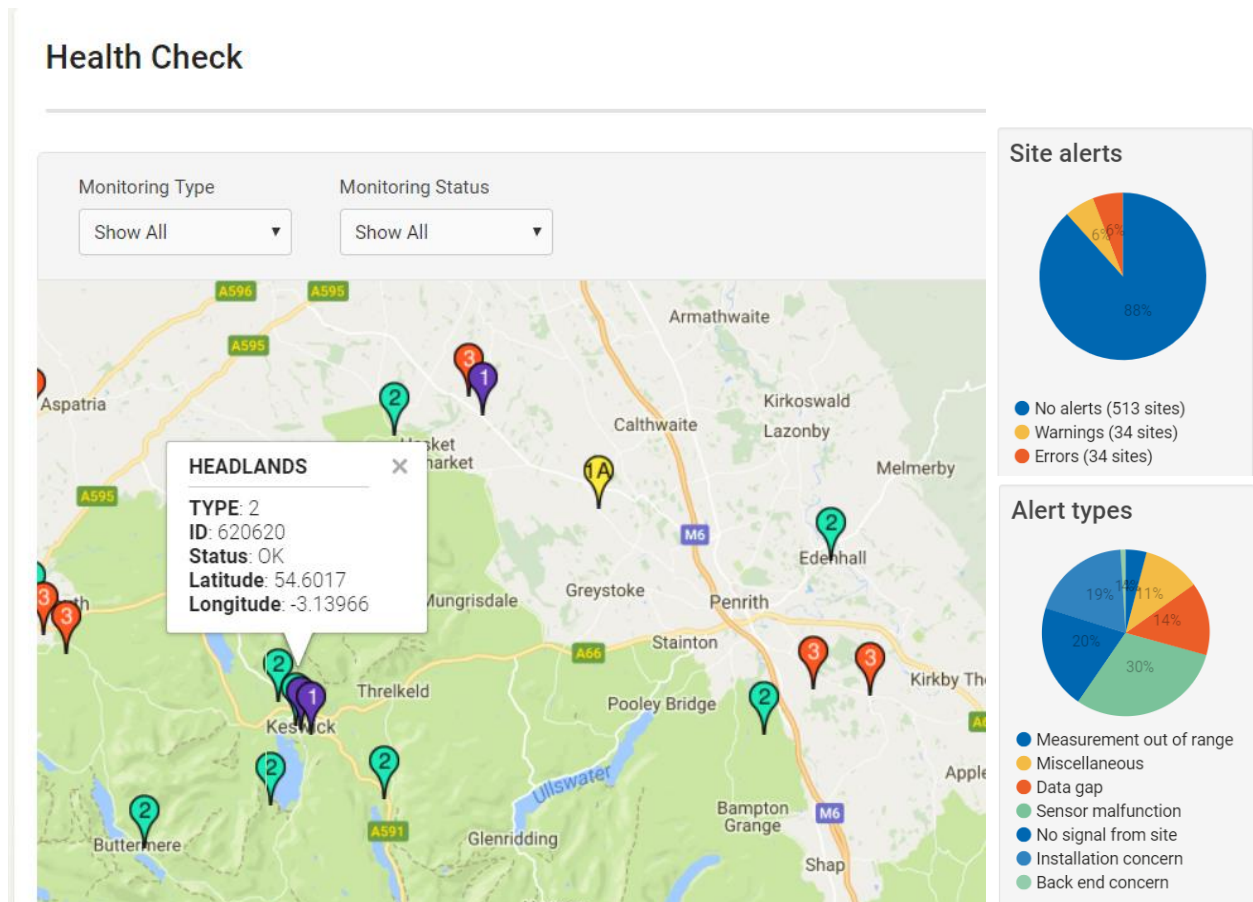
The image below shows sites displayed by monitoring type:

- **Type 1** – Monitoring includes temperature of key assets, ambient temperatures, and three phase power monitoring.
- **Type 1A** – Monitoring includes temperature of key assets, ambient temperatures, three phase power monitoring, and internal transformer temperature monitoring.
- **Type 2** – Monitoring includes temperature of key assets, ambient temperatures, and single phase power monitoring.
- **Type 3** – These are pole mounted transformer sites. Monitoring includes temperature of transformer, ambient temperature, and three phase power monitoring.

The upper pie chart shows the proportion of sites that have no alerts (blue), have alerts classed as 'warnings' (yellow), and have alerts classed as 'errors' (red) associated with them. Note that many sites may have more than one alert against them.

The lower pie chart displays the category of the alerts across these sites. These alerts include 'data gap', 'sensor malfunction', and 'installation concern' amongst others.

4.1.2 Sites Summary Screen

The sites summary page includes visual indications of equipment communications connectivity and data completeness. In the image below, each row in the table represents a site, displaying key site information.

The key information on this screen is as follows at this point in time:

- **Site indication spot** – shows the status of the site. Grey indicates 'to be installed' or 'in progress', green indicates 'OK', yellow indicates 'aborted' sites, for example if the site has been decommissioned.
- **Hub indication spot** – shows that the site has data connectivity to the back end, with green indicating connectivity.
- **Sensor position spots** – each spot indicates a sensor position, and it is coloured to indicate data completeness. Green indicates complete data, yellow indicates minor data gaps, and red indicates more serious data gaps. Grey indicates that the position was not installed.
- **Measurement data completeness indicator bar** – this bar represents the completeness of the data from that site for the last week. Green indicates data was received, red indicates a gap. The grey sections of bar show where the daily data report has not yet been received, and is not expected yet. Note that this is an indication that at least some data was received for that period, not of how complete that data is. For example, individual sensors may not be sending data, but this indication will still show green.

There is a more detailed site screen that can be accessed by clicking on the site in the summary screen. This more detailed screen 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 this screen is shown below.

BACK CALEDONIA ST (#231180)   < back to site list

Location: 53.5683 / -2.45136

Type: Type 2
Status: OK
Last update: 2018-01-08 09:15
Hubs: 🟢 C17960A0948
Alerts: 🔴 System - Missing site data
Photos:

Thermal photo   Thermal photo
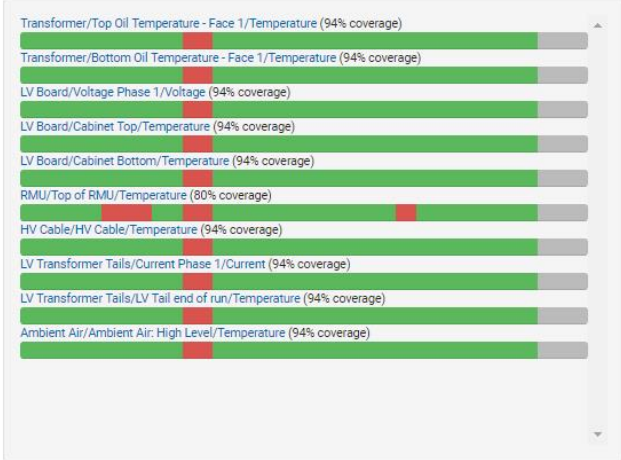
Component group 1, transformer

The sensor coverage panel lists:

- Transformer/Top Oil Temperature - Face 1/Temperature (94% coverage)
- Transformer/Bottom Oil Temperature - Face 1/Temperature (94% coverage)
- LV Board/Voltage Phase 1/Voltage (94% coverage)
- LV Board/Cabinet Top/Temperature (94% coverage)
- LV Board/Cabinet Bottom/Temperature (94% coverage)
- RMU/Top of RMU/Temperature (80% coverage)
- HV Cable/HV Cable/Temperature (94% coverage)
- LV Transformer Tails/Current Phase 1/Current (94% coverage)
- LV Transformer Tails/LV Tail end of run/Temperature (94% coverage)
- Ambient Air/Ambient Air: High Level/Temperature (94% coverage)

4.1.3 Alerts Screen

Another function on the system health dashboard is the alerts functionality. 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. These 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.

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.

4.1.4 Hubs Screen

The Hubs screen shows a summary of the activity of each sensor hub, including if communication has been established, the firmware version, the time of the latest communication, and the battery level. Further detail screens allow access to the communications history of each sensor hub.

This allows users to review the communications to and from the Hub, and trouble shoot issues.

4.2 Data Dashboard

This interface provides access to the data collected within Celsius. This 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).

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.

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.

4.3 Commissioning Application

The commissioning application supports the collection of site data and the installation of sensors. The Celsius sites are pre-loaded into the system with known information such as name, ID number, location, building type, and transformer age and specification. A list of the sites can be accessed, sorted by installations status from 'to be done', 'in progress', 'done', 'problematic' and 'aborted'. Sites are found by scrolling through this list, or searching at the top search bar. A screenshot of this application page is shown in the image below.
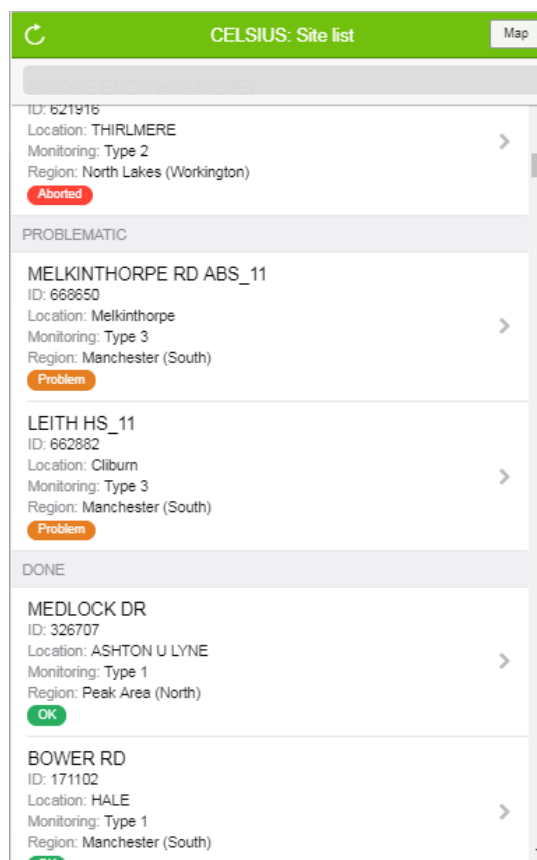
When a site is selected, the known information is displayed for checking, and additional information collected from drop-down lists and text boxes. Photos can be taken and stored for the site, including thermal image photos. One of these site information screens in shown in the image left most below.

The application then displays the list of sensor positions that are needed for that site, and allows a user to add a hub by scanning or entering its barcode. The user can then work through the list of required sensor positions and add sensors by scanning or entering their barcode. Commissioning the equipment results in an initial sensor reading to be sent to the data management back end, and this is then displayed on the application for the user to check. This important step allows users to check if the sensors are working before they leave site. The sensor list screen is shown in the right most image below.
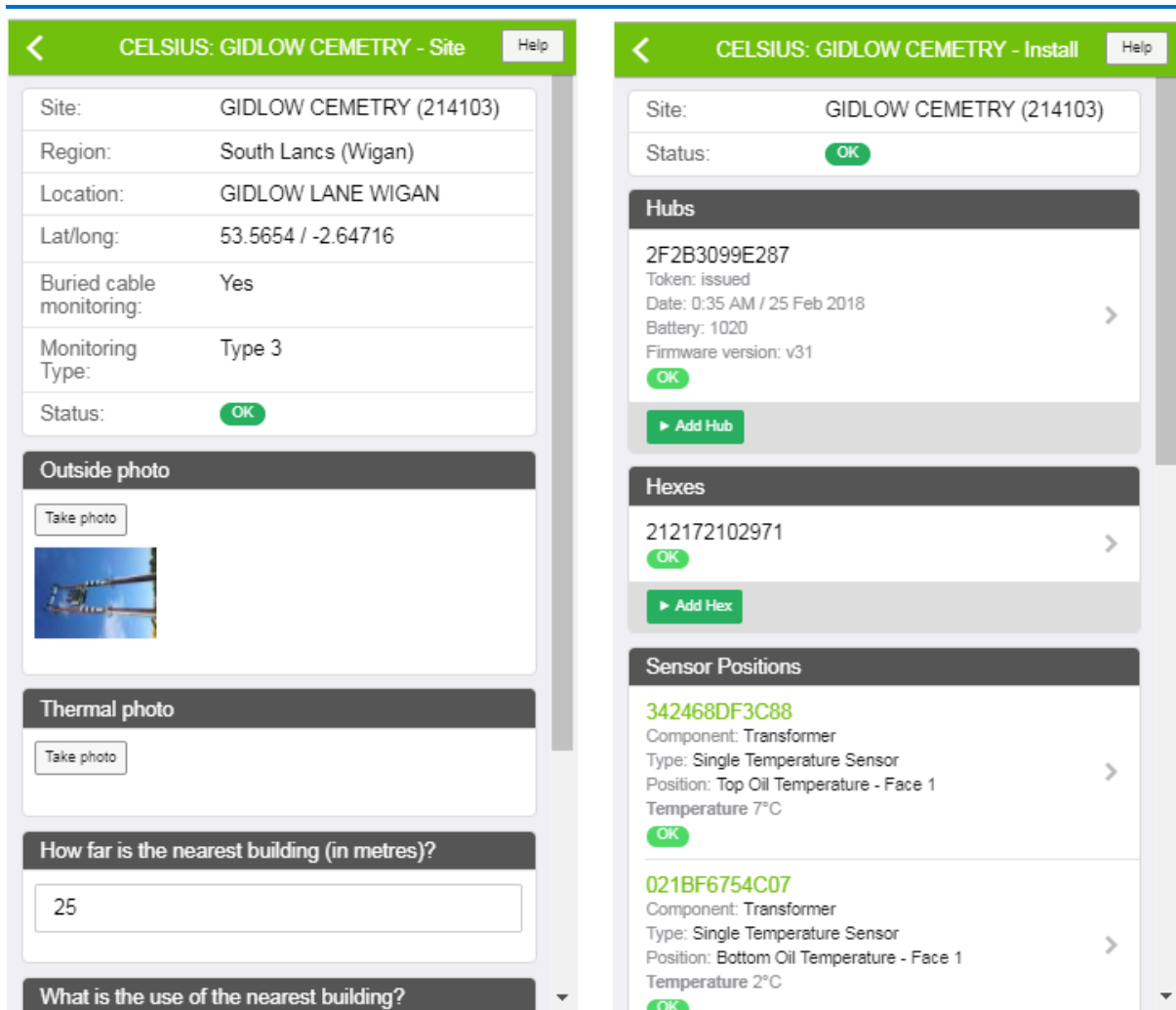
4.4 Admin pages

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.

A data collection log is also available on these pages.

4.5 Ongoing development

While the data management site is largely complete, there are updates and improvements that are being made on an ongoing basis. These include:

- **Updates to automatic alerts** – Alerts are generated automatically according to a set of rules. This enables that large amount of data coming in to be processed to search for potential data or site issues. The rule settings must be considered carefully to prevent either a large number of alerts raised when they are not needed, or issues not being flagged. This is particularly necessary when

new issues are discovered and need to be identified. Therefore, these rules are reviewed and updated regularly.

- **Weather data** – Weather data is an important input into the Celsius project, and access to weather data (e.g. ambient outdoor temperature, wind speed and direction, humidity) alongside Celsius data will enable analysis to be more effective and efficient. This functionality is being added, through the use of a free weather data network.

- **Site performance improvements** – continuous improvements are being made to the performance of the site. For example, improvements to the loading times of particular screens are being made, particularly those that require a significant amount of data such as the sites pages.

- **System malfunction warnings** – An issue with the data receiver or processing can result in gaps in the databases across all sites, and therefore is a serious issue. While these issues are identified quickly through the teams who are using the site daily, a more formal warning system is being put into place to ensure that issues are recognised and fixed as soon as possible.

5 Issues and solutions

A number of issues with sensor and data management technology have occurred and whilst they have been solved, it is important to record these issues and the solutions deployed to ensure that learning is preserved. This section summarises the main issues experienced since the previous data update in May 2017.

5.1 Data gaps in Hex data

Hex data is the data collected by the Hex sensor equipment, including current, voltage and temperature flying leads. It was identified that data gaps in this data was common at particular sites. Upon further investigation, it was discovered that these sites had three or more Hex units within a single site.

Upon discussion with Ash Wireless, the providers of the Celsius monitoring equipment, it was discovered that there is an upper limit to the permissible Hex units on a site, which was originally two per site. Firmware changes have been made to raise this to 3 per site, which allows most realistic configurations. Once this update was in place, the issue was solved.

5.2 Mislabelled data

This issue has been found in a number of sites where current data has been misclassified as voltage. As this resulted in no power calculations taking place, it was clear that the issue was on the site. After some investigation by Ash Wireless, it was discovered that there was an issue with a small proportion of the Rogowski coils used as current sensors. This issue was fixed by replacing these sensors. This issue was identified through a search of the data logging in the management system, and only three instances were identified.

5.3 Low current readings

It was identified that some sites were erroneously reporting low currents. The sensor equipment at some sites was returned to Ash Wireless for investigation, and it was discovered that there was an issue with some Hex units where the pins were not soldered correctly. This meant that the sensor did not read correctly, and only noise is reported. This also meant that very high current harmonics were reported.

In order to identify this issue, an automatic alert was set up which looked for the combination of current data of less than 15A, and a Total Harmonic Distortion reading of more than 300%. To date, this alert has identified 21 instances of this issue across the sites. The list of problem sites is with Ash Wireless for resolution.

5.4 Data gaps across all sites

There have been three instances of data gaps across the whole project.

One of these was due to the receiver failing, meaning that while data was being sent, it was not being picked up by the data system. The solution here was for the receiver to be re-started, and as the issue was picked up within a few hours of it occurring, little data was lost. The sensor hubs are able to store up to 7 days' data,

and the data management system can request data to be re-sent to backfill gaps. This system was effective in filling gaps caused by the receiver failure.

The other two instances were due to an issue in the analysis of data once it had been received and stored. This caused the data management interface to indicate there were data gaps even though the data had been received. The cause of this was a software update implemented into the back end that had an error in it. Again, in both instances, the data backfill approach meant that the gaps were filled.

To help minimise the impact of these issues in future, an additional alert will be added to the system that will notify key personnel via email of data gaps across all sites. This will allow significant issues to be resolved as soon as they occur.

5.5 Commissioning data not showing correctly

The intended functionality of the installation application included the initial values from the sensors displaying in the application so that they can be checked before the installers leave site. In reality, this was not always occurring, and data was being reported as default numbers (for example 0°C), or not at all. It was discovered that these sensors started working after this initial reading ready for the next daily report.

It was decided that as the installation process is complete, this issue will not be fixed within the Celsius project.

5.6 Voltage out of range

An issue has been identified in certain sites were voltage readings are outside the expected voltage boundaries. Two types of issues were identified:

- **Sensor issues** – where the voltage data reported is 200V or below, it is assumed that there is a voltage sensor issues. The most common issue is the connection of the neutral sensor which can be unreliable.
- **Site voltage issues** – occasionally, data is recorded for voltages at sites which is outside the statutory limits. These cases are passed to Electricity North West.

6 Celsius Cooling Trial Requirements

The next stage of Celsius is a trial of retrofit cooling technologies in 100 of the Celsius trial sites. The technologies to be trialled include:

- Solar shade
- Reflective paint
- Improved passive ventilation (GRP)
- Improved passive ventilation (Brick)
- Improved passive ventilation (Non-standard)
- Forced ventilation (positive)
- Forced ventilation (negative)

Most of these technologies are passive (i.e. have no moving or powered parts). For the sites where these technologies are deployed, the existing sensor arrangement is sufficient for the cooling trial. However, the two forced ventilation technologies are active, including fans to move air around a substation. In the sites where these technologies are deployed, additional sensors are needed to indicate the operation times of the technology. It may also be beneficial to add additional temperature sensors to monitor its effectiveness. There are two possible methods to achieve this:

- **Additional K^{e}LVN sensors** – the K^{e}LVN suite of sensors includes a wedding ring CT which can be used to clamp around the power supply lead for active technologies to record the operation. Additional temperature sensors can be added as required. To enable this to happen, additional sensor positions will need to be added to the installation application, allowing the sensors to be added to the site. The overall configuration of sensors will have to be carefully considered to ensure that it does not exceed the maximum configuration per site of 30 sensors, where up to three are Hex units.

- **Technology specific data collection** – it is possible that the technologies to be installed have data collection capabilities, and this data can be used to assess its performance. This data is likely to be more detailed, and therefore could bring additional insight. Brining this data into the Celsius data management system should be possible depending on the arrangement of the technology on offer. For example, if the data is collected locally, is could be sent with an additional modem communicating to the Celsius receiver. Alternatively, if there is an existing technology specific data web service, the Celsius system can gather data from there.

The next steps are to understand what data is needed from each site and technology type, and to understand what is on offer for each of the technology types. While the required changes are likely to be simple and achievable, it is recommended that they are scoped and understood as soon as possible to ensure they are in place in time for the installation of these trials, planned for April 2018.

7 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.

Some further functionality and improvements are still being developed and added, including performance improvements, tightening automatic validation rules, and bringing in weather data. As issues are discovered, solutions are deployed as quickly as possible.

A small amount of additional functionality is likely to be needed to support the next stage of the Celsius trials; the retrofit cooling technology trial. While the required changes are likely to be simple and achievable, it is recommended that they are scoped and understood as soon as possible to ensure they are in place in time for the installation of these trial, planned for April 2018.