BAU Monitoring Solution Specification

Specification of the monitoring solution to implement the findings from the Celsius project into Business as Usual (BAU) within GB Distribution Network Operators

Report for Electricity North West

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1 Introduction

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 close in March 2020.

A key aim of the Celsius project was to develop a methodology for determining a more informed transformer rating for low voltage distribution transformers, 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 assumed. 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.

The Celsius project trials and analysis involved 520 11kV and 6.6kV / Low Voltage (LV) ground and pole mounted distribution substations, each of which was fitted with at least one central communications hub and up to 30 sensors measuring asset and ambient temperature, voltage and current. Information was gathered on the characteristics of the substation equipment, building type and its installation environment. Weather data, for example ambient temperature, precipitation and wind speed, was also gathered from the nearest Met Office measurement point. The data and information were analysed together to determine more informed ratings and investigate the relationship between asset environment and operating temperature. These findings were reported in a separate report called Secondary Network Asset Temperature Behaviour Report, delivered in September 2019.

It is intended that the learning developed during the Celsius project should be translated into Business as Usual (BAU) operation within ENWL and other GB Distribution Network Operators (DNOs), in order to increase the capacity available within the LV distribution networks. This is particularly beneficial as the demand on networks is expected to increase with the uptake of low carbon transport and heat technologies, thus additional capacity will enable the accommodation of a greater amount of load before network reinforcement is required.

The purpose of this document is to describe the specification and requirements of a BAU monitoring solution which will be deployed into substations and will allow more informed ratings to be estimated. Once the findings of the Celsius project are finalised, and the intended BAU integration is agreed within ENWL, the relevant internal procedure documentation, procedures and training will be updated and developed and deployed. Included in the report is:

- Section 2: Celsius BAU process – this section describes the proposed changes to the existing BAU asset management process to incorporate the Celsius methods. It also details the benefits of the Celsius solution over the current processes.
- Section 3: Celsius BAU monitoring solution topology – this section describes the monitoring solution required, including the numbers and locations of monitoring equipment
- Section 4: Celsius BAU monitoring equipment functional specification – this section describes the specification monitoring equipment required
- Section 5: Further work – this section describes the additional work required within the Celsius project to advance the Celsius BAU process towards implementation, and the recommendations for further work beyond the project to maximise benefit from the work.

2 Celsius BAU process

This section describes a proposed approach to incorporating the learning from the Celsius project into the present BAU asset management processes. This has been developed with close reference to the present asset management processes for distribution substations and transformers, as practiced by ENWL. The development of these processes aimed to maximise the benefit from the Celsius project whilst making only minor updates to the present BAU processes in order to allow ease of adoption within ENWL, as well as within other GB DNOs.

2.1 The current asset management process

Figure 1 below summarises the current asset management process.

Data collection, storage and reporting

Data stored in Ellipse:

- Nameplate data recorded
- Nominal rating is used in all circumstances
- MDI, spot temperatures, and condition updated at least every 60 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

Uses experience to determine if intervention is necessary and selects options based on cost. Data is collected to validate MDIs.

Intervention

Interventions include:

- Do nothing (i.e. assessment has determined that no action is needed)
- Reconfiguration of surrounding network
- Transformer replacement / additional substation
- Refurbishment of assets*
- Maintenance / defect management*
- Forced cooling*

*note – These interventions may be adopted as asset management, but do not improve the health score in CNAIM.

Figure 1: Summary of the ENWL Asset Management process as it is today

The current asset management process consists of four main steps:

- **Data collection, storage and reporting** – data is stored in the asset database, which is then used for reporting and influencing planning and asset management decisions. This includes use in Common Network Asset Indices Methodology (CNAIM), a standard model for GB DNOs which produces asset health and risk indicators which are reportable to Ofgem. These assessments can also be used to influence asset management decisions. Key data related to this project include:
    - **Rating**: For distribution transformers, the nameplate rating is used in all of these processes.

  - **Maximum Demand:** This is collected from a Maximum Demand Indicator (MDI) on the LV board during regular inspections every 1 to 5 years. The indicator records the maximum half-hourly average demand since the indicator was last reset, and for distribution transformers is often the only indication of LV load on that transformer. There are limitations to the recording of these readings, due to the manual process of recording and resetting, possible issues with recording short durations of high load that are not representative of the normal demand (for example, backfeeds during fault conditions), and the possibility that the instrumentation may be faulty.
  - **Transformer surface temperature:** Spot temperature readings are taken during regular inspections every 1 to 5 years. A single temperature is recorded for the transformer. It is likely that multiple readings are taken, and the highest is recorded.
  - **Oil samples:** Oil samples have not traditionally been taken from secondary substation transformers in operation except in very rare cases where there are signs of overheating, so there is no history of oil samples for operational transformers. There is a new practice of taking oil samples for some older transformers, which will build up data records.
  - **Asset expected life:** An expected asset life is assumed across all distribution transformers in GB, as defined within the CNAIM process.
- **Trigger for intervention decision** – There are many potential triggers that will flag a site for potential reinforcement or other intervention:
  - **Load growth:** Demand from existing loads can change over time, and when this grows over time, the network may need reinforcing to adapt. This would be picked up through an increase in the demand readings.
  - **Connection request:** A new connections request will trigger studies to determine what reinforcement or intervention, if any, is required to support the new load or generation.
  - **Network referral:** Issues can be identified during regular inspections or other notification, for example, damaged or degraded equipment.
  - **Asset health score above threshold:** The asset health score produced by the CNAIM model can be used to trigger asset management decisions and prioritise the order in which sites are assessed for intervention.
  - **Asset failure:** Asset failure due to fault, which may be caused by numerous factors including loading.
  - **At risk asset types:** Rarely, particular asset types are identified as being defective or at risk, and a systematic replacement scheme will be implemented.
  - **Non Trading Rechargeable (NTR) and diversion projects:** The requirement to move network assets may be triggered by developments or customer requests which are unrelated to demand or technical triggers.
- **Decision for intervention** – Intervention decisions are made by the relevant team (asset management, capacity strategy and connections) by collecting and validating the relevant information. Where a demand reading from an MDI device is being used, this is often validated using a load data logger which is installed onsite for a number of weeks, and the data analysed, including consideration for seasonality. The decisions for intervention will be made by comparing the available options for cost effectiveness.
- **Intervention** – There are a number of interventions that are currently implemented as required:
  - **Do Nothing:** It is possible that further investigation shows that no action is needed.
  - **Reconfiguration of surrounding network:** Reconfiguration could allow load to be supported by other nearby substations with minimal additional investment.
  - **Maintenance / refurbishment:** Other interventions include refurbishment of assets, maintenance, defect management, and forced cooling. Though these interventions may help to support the operation of the equipment, they do not impact the CNAIM asset risk scores.
  - **Transformer replacement / additional substation:** Physical reinforcement of the network may include replacement of transformers with transformers with a higher

rating, installing additional transformers into existing substations, or building new substations.

This process is being updated and adapted over time as the requirements of the system change, and new technologies and techniques are incorporated. Potential upcoming changes to this process include implementing oil sampling on older distribution transformers, reviewing the approach to MDI specification to incorporate digital instrumentation, and further development of active management approaches. The regulation in this area may also adapt over time, and specifically it is likely that there will be changes to the CNAIM model in RIIO ED2.

In a similar way, the findings from innovation projects like Celsius can be incorporated into these processes, leading to continual improvement.

2.2 Proposed process incorporating Celsius

In a BAU process that includes the Celsius method, there will be distribution substations that have additional monitoring and can be treated slightly differently. Within this document, these sites are referred to as 'Celsius sites'.

Celsius monitoring will be installed when a substation has been identified for load or temperature issues.

Note: Celsius should only be considered when there are no time constraints around the intervention (e.g. in a connections request). However, if the Celsius monitoring data already exists it can be used to support the planning study.

The approach used to determine the configuration and specification of Celsius monitoring was to use minimal monitoring points to develop a practical improved rating. Learning from Celsius project analysis was used to identify the most suitable monitoring positions. Celsius monitoring consists of:

- Transformer surface temperature measured at the top oil level
- Ambient temperature measured away from the transformer or other heat or ventilation sources
- Transformer demand measured through three phase current and voltage sensors

The monitoring data will allow calculation of a more informed rating, or 'Celsius rating' which is determined by estimating the hotspot temperature within the transformer and comparing this with demand. This rating will be more accurate than the conservative nameplate rating which is set by the manufacturer based on assumed operating conditions. In most cases, the Celsius rating will be higher than the nameplate rating. The methodology of estimating hotspot temperatures and calculating Celsius rating have been developed and reported under the deliverables of the Celsius project.

The Celsius rating can be used in planning, asset management, network capacity and connections decisions, to enable the support of greater load growth without the need for network reinforcement.

This new rating and more accurate demand and temperature data will be used in the CNAIM model, allowing a more accurate indication of asset health and risk potentially lowering the number of sites being referred for intervention.

The data can also be used to produce notifications to warn of any issues developing, e.g. unexpected temperature rise. These notifications will be carefully tuned to support timely reaction to warning signs of failure, without over-triggering. It is envisaged that the notification will be sent as an email or SMS to key members of ENWL and will indicate if the site needs visiting urgently.

The Celsius monitoring data can be used to enable optimised selection of intervention and to monitor the resulting benefits. Interventions can include but are not limited to:

- retrofit cooling technologies such as those tested in the Celsius project
- demand side response
- network meshing
- network reconfiguration
- traditional reinforcement

Figure 2 below summarises the new asset management process which incorporates the outputs from the Celsius project. It shows all of the elements in the current process, with the new processes highlighted in the green boxes.

Data Collection, storage and reporting

Data stored in Ellipse:

- Nameplate data recorded
- Nominal rating is used in all circumstances
- MDI, spot temperatures, and condition updated at least every 60 months

Determine Asset Risk 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)

Criteria:

- The issue is temperature / load related and not time limited
- The asset is fit for purpose (not about to reach end of life)
- There is a positive CBA and carbon evaluation for the application of Celsius in this case
- Validated Celsius methods have been developed for that type of asset and context

Yes

Celsius monitoring installed, more informed rating calculated

Further analysis and CBA informed by Celsius data to identify the most appropriate intervention

No

Decisions made by comparing business cases of technically appropriate solutions. Data is collected to validate MDIs.

Intervention

Interventions include:

- Allow loading to Celsius rating
- Install retrofit cooling solution
- Reconfiguration of surrounding network
- Transformer replacement / additional substation
- Refurbishment of assets
- Maintenance / defect management.

Intervention

Interventions include:

- Do nothing (i.e. assessment has determined that no action is needed)
- Reconfiguration of surrounding network
- Transformer replacement / additional substation
- Refurbishment of assets
- Maintenance / defect management
- Forced cooling

Figure 2: Summary of the ENWL Asset Management process incorporating Celsius learning (in green)

When a non-Celsius site is flagged for an intervention, the first step is to decide if it is economic to deploy the Celsius monitoring. It is expected that the Cost Benefit Analysis (CBA) will be positive in most situations, particularly if the issue is load or temperature. This is because the Celsius monitoring is easily deployable and low cost once the procurement, communications and IT integration is established, and it will be able to quickly confirm the demand and temperature.

As in today's process, the maintenance team will make a decision about what, if any, intervention is required, and this will include the CBA for installing Celsius monitoring. As the decision for intervention becomes more complex, it is expected that the decision process will have to develop as well. The approach envisaged here is that there will be standard CBAs and carbon cases that can be applied easily to common situations, enabling quick decisions making and minimising the additional workload in developing new analysis for each application.

After Celsius monitoring has been installed for a period of time, initial assessments of the more informed rating can be made which can then be updated over time as more data is collected. This will determine the potential of capacity which can be released through the Celsius methods and allow assessment of the interventions.

The Celsius project developed methods to calculate a more informed rating for transformers. There are some potential gaps in the range of sites covered by the work to date, e.g. outdoor or Glass Reinforced Plastic (GRP) substations. Further work is required to develop methods for these categories of sites, but insight can be gained from deploying the monitoring even at these sites.

The asset database shall include the Celsius rating so that the asset management, planning and connections teams are aware that the substation has a modified rating. Labelling shall be deployed on site to highlight that the nameplate rating is not correct and refer staff to the asset database for the Celsius rating.

The Celsius methods should not allow a transformer to operate beyond its design temperature but as this is a new way of determining the operation of a transformer the probability of failure needs to be carefully considered. It is likely that the risk of failure will be reduced because of the monitoring and the notifications will be tuned to support timely reaction to warning signs of failure. Post-mortems shall be carried out on failed equipment at Celsius sites and compared with non-Celsius equipment and, if necessary, the Celsius process should be updated.

2.3 Benefits of Celsius BAU solution and process

There are several benefits of the Celsius BAU solution, including:

- **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.

3 Celsius BAU monitoring solution topology

This section will discuss recommendations on the location of monitoring equipment within Celsius substations.

3.1 Celsius project monitoring learning

There was an extensive monitoring trial as part of the Celsius project. The monitoring arrangement for the ground mounted substations included in the trial is shown in Figure 3 below.

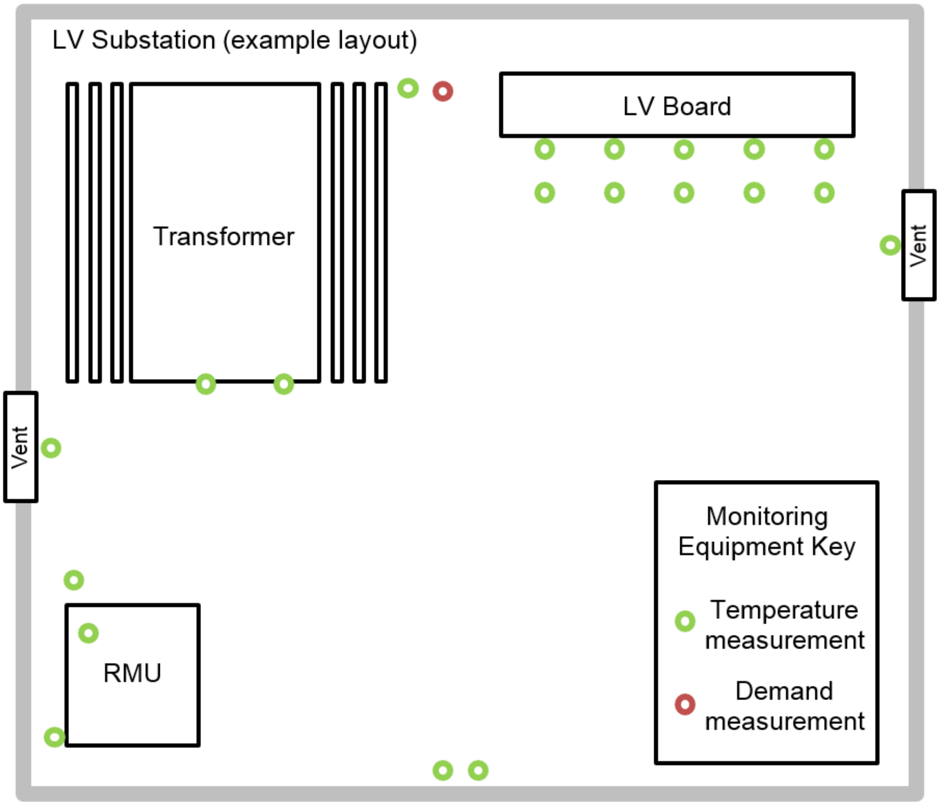

Figure 3: Celsius project monitoring topology

Sensor locations vary between sites, depending on the site configuration.

Temperature monitoring included:

- Transformer surface temperature at the top oil and the bottom oil levels, and in some cases several measurements are taken at the top, mid and bottom oil levels.
- Any HV cables and LV transformer tails accessible.
- LV ways where they are notably loaded.
- In some sites, buried cables under the backfill or within the duct.
- The RMU or HV switchgear where accessible.
- The ambient temperature in the substation at a high and low level.
- The ventilation air temperature at a high and low-level vent for indoor substations.

Demand measurement varies between sites. Some sites have three phase monitoring, including harmonics and unbalance, of voltage and current. This is then combined into full three phase complex power. The remaining sites have only single-phase monitoring, including voltage and current, harmonics, and calculated complex power.

Where possible, the transformer demand was measured at the transformer tails (as indicated above), but when this was not possible, e.g. where the tails were not accessible, the demand was monitored on each of the LV ways. Only single phase monitoring was used in these cases.

The data collected for the Celsius project was used to generate learning and methods for determining a more informed rating and assessing the impact of environmental conditions on the thermal performance of the substation equipment.

Key learning relevant to identifying the most appropriate monitoring approach in BAU includes:

- A more informed rating can be developed using only transformer load, surface temperature at top oil level, and ambient temperature at high level. Additional data may increase accuracy of the calculation, but this impact is not significant and so it is recommended that no more monitoring is required.
- Location of the monitoring units is important, and should be as replicable between sites as possible, to ensure results can be standardised and compared.

3.2 Recommended Celsius BAU monitoring topology

The recommended configuration of BAU Celsius monitoring is illustrated in the diagram in Figure 4.

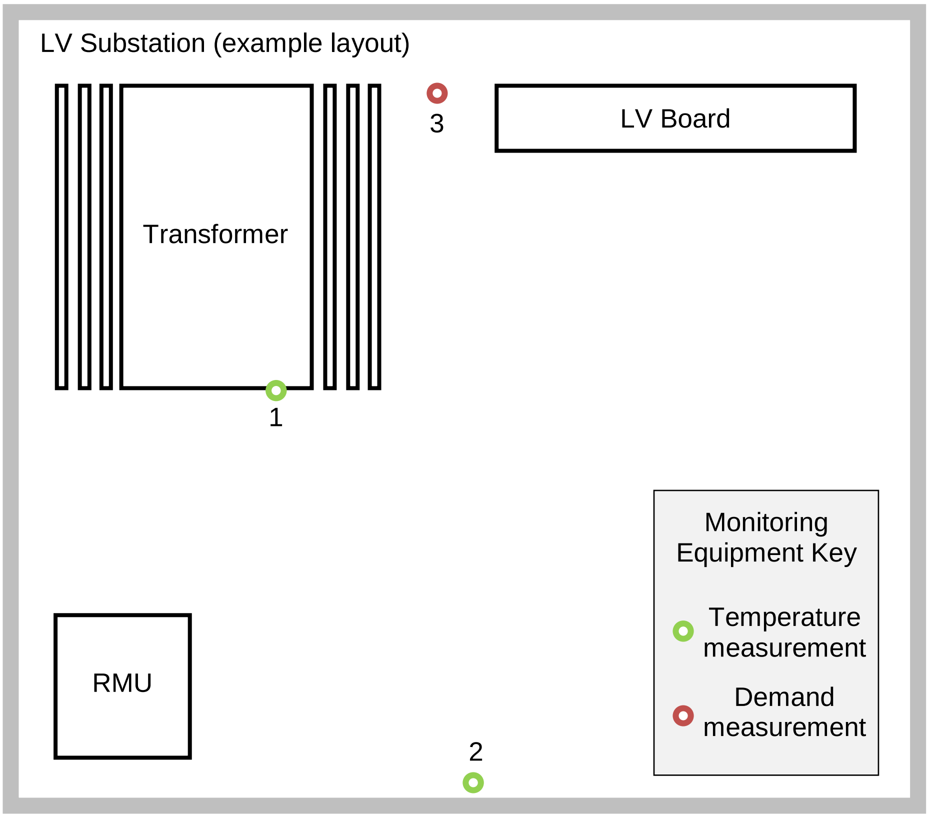

Figure 4: Recommended Celsius BAU monitioring topology

The sensor locations show in Figure 4 are as follows:

1. Transformer surface temperature sensor, located at the top oil level, near the corner of a transformer.
2. Ambient air temperature sensor, located at ~2m high, and away from the transformer, any other sources of heat, and any ventilation.
3. Transformer demand measurement. This could be implemented in several ways depending on the layout of the substation. Where available, transformer LV tails should be monitored for three phase voltage and current. Alternatively, demand could be measured on the LV ways, or through existing instrumentation.

4 Celsius BAU monitoring equipment functional specification

This section will discuss recommendations on the functional specification of the monitoring equipment to be used for the Celsius BAU process.

4.1 Celsius project monitoring learning

The Celsius project primarily used the K^{e}LVN monitoring solution, provided by project partners ASH Wireless, to provide monitoring data for the project. This solution is illustrated in Figure 5 below.

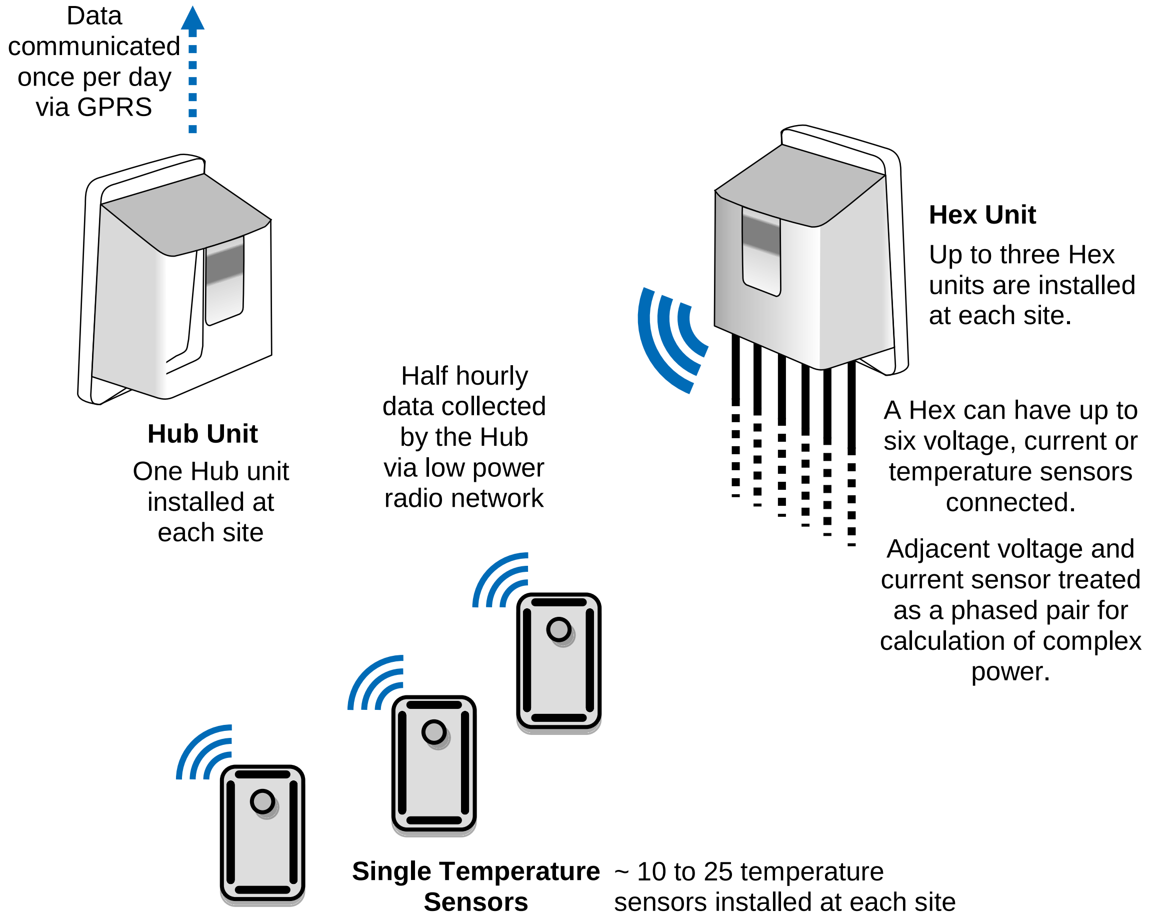

Figure 5: Overview of the K^{e}LVN monitoring system used in the Celsius project

The data collection system gathers data from a variety of sensors to a Hub, and reports this to a back-end data analysis system. The solution is designed to be flexible to adapt to the requirements of the site. Up to 30 sensors can be installed, including multiple temperature sensors, and up to three Hex units, each of which can support up to six voltage, current or temperature sensors on leads.

The main components of the substation network are:

- **Single Temperature Sensors** measure the temperature at a specific point, this can either be ambient conditions of the surface temperature of particular assets. The temperature sensor is specified to within 0.1°C resolution, and an absolute accuracy of ± 1°C. The measurement accuracy shall hold over the range 0°C to +85°C. The unit is designed to IP67 environmental sealing.
- **Hex Sensor units** can be used to monitor 6 independent inputs using flying leads to measure Temperature, Voltage and Current. Hex Sensor units can also be configured for Power Measurement and use paired Voltage and Current Flying Leads to measured power on 3 phases. Voltage readings are accurate to ± 1V over the range 220-255V. Current

measurements are in the range 0-2000A with 1% full scale accuracy. Voltage and current are measured every 30 seconds, and the average of these readings over 30 minutes is recorded as the reading. The temperature sensor is specified to within 0.1°C resolution, and an absolute accuracy of ± 1°C. The measurement accuracy shall hold over the range 0°C to +85°C. The unit is designed to IP65 environmental sealing.

- **The Hub** acts as low power radio concentrator and has cellular modem. This unit collects the data from the sensors onsite. Once per day it sends the data to the monitoring data management system.

A key design feature of the K^{e}LVN solution was the ease of installation; the substation equipment can be installed in a non-intrusive manner, without having to take any equipment off line, using magnetic or tie wrap mounting and can be configured quickly and simply. Wireless communication of data onsite means that there is minimal need for wiring, which helps in the ease of install, and prevents trip hazards in the substation. The monitoring equipment is battery powered to alleviate the need to provide an LV power supply, and the system is capable of operating for 3 years without a battery change.

The installation of the monitoring equipment is supported by an application linked to the data management back end system. This application allows the position of sensors to be linked to the sensor serial number, which means that the sensor data is labelled correctly as it comes into the system. The application also allows collection of any other useful site information and photos and provides initial readings of each sensor position allowing commissioning of the system to be validated onsite before installers leave.

Sensors and Hubs have 3 modes of operation: Off, Normal Operation and Test Mode. Units are turned on and temporarily switched into Test Mode by use of a magnet. Test Mode is enabled to assist in the installation and configuration of the local network.

It is notable that the temperature measurement accuracy only covers operation temperatures up to 85ºC. This was appropriate for the project as there were not temperatures significantly above this level, however, this is lower than the maximum operating temperature of the transformer (105ºC for cyclic load profiles). It is recommended that the operation temperature of temperature monitoring should be 100ºC.

Voltage and Current data is recorded as 'Route Mean Squared', which is determined from a high frequency (2.5kHz) measurement of the waveforms. An RMS measurement is taken every 30 seconds, which is then averaged to produce the half-hourly values. This was compared with the results of a standard data logger used for current measurement, which takes a measurement every 5 minutes and produces an average. This comparison was performed over two sites, for all three phases. An example graph of results of this comparison is presented in Figure 6 below. This graph shows that the data is very well matched, and in practice, the average difference between the data collection was only a few percent. This shows that in the BAU monitoring solution, a data sampling of 5 minutes to produce half hourly voltage and current readings is likely to be adequate.

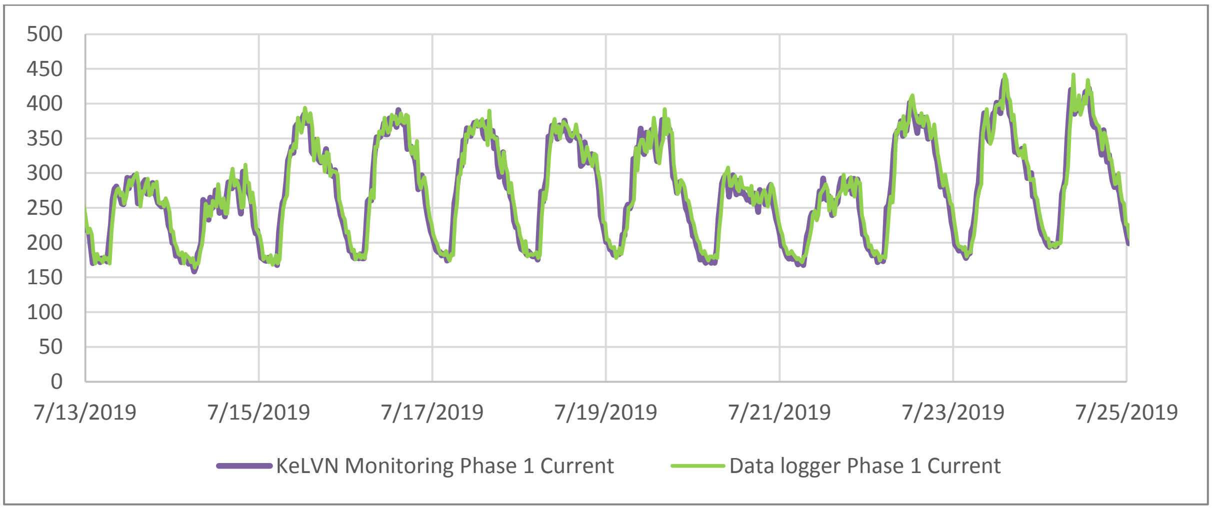

Figure 6: Current readings from KeLVN system and validation data logger for an example site

The Celsius analysis was most successful for sites with three phase monitoring, with single phase monitoring sites being less likely to produce valid Celsius ratings; therefore, three phase power monitoring is important for the BAU process.

Investigations could be done into the requirement for voltage readings to consider if the voltage can be assumed to be balanced across phases (thereby reducing voltage measurement to single phase), or even if the voltage can be assumed to be constant at a set value. It is notable, however that the general trend across the substations observed that the voltage is generally not set at 230V, and is more often much higher than this, so assuming nominal voltage without at least a spot reading is not advisable. The advantage of eliminating the voltage reading from the BAU monitoring would mean that the installation is simpler, and the cost of equipment is reduced. However, voltage measurements would allow the Celsius rating to be more accurate, and there could be additional advantages for recording this data.

Key learning relevant to identifying the most appropriate monitoring approach in BAU includes:

- It is advantageous to have a sensor solution that is easy to install and can be implemented in the full range of substation configurations, including:
    - Wireless data communications within the substation so that installers do not have to route wires during the installation
    - Installation application ensuring easy positioning and commissioning of equipment, and that the installation process is as replicable as possible
- Temperature, voltage and current data collection at a suitable accuracy and frequency to produce valuable results to support the Celsius BAU process.
- Remote data collection is essential to the implementation of the Celsius BAU process to support development and update the Celsius rating.
- It is essential that system updates can be done remotely. This supports bug fixes and updates to the operation of the monitoring equipment.
- Three phase current monitoring is required for accurate Celsius ratings.

4.2 Recommended Celsius BAU monitoring functional specification

The key functional specifications for the Celsius BAU monitoring equipment is as follows:

- Temperature measurement shall be accurate to 0.1°C resolution, and have an absolute accuracy of ± 1°C. The measurement accuracy shall hold over the range 0°C to +100°C. Temperature readings shall be taken every 30 minutes.
- Voltage readings shall be accurate to ± 1 V over the range 215-260V. Voltage RMS measurements shall be taken at least every 5 minutes, and the average of these readings over 30 minutes shall be recorded.
- Current measurements shall be in the range 0-2000A with 1% full scale accuracy. Current RMS measurements shall be taken at least every 5 minutes, and the average of these readings over 30 minutes shall be recorded.
- All data shall be transmitted to the data collection system at least once per day
- All equipment shall be at least IP65 rated for environmental sealing, with IP67 rating for more vulnerable components such as Rogowski coils.
- The monitoring solution shall be designed for ease of installation, e.g. fixings via magnets or ties, wireless communications within the site, long life battery or scavenged power supply to limit onsite alterations, installation process supported by an installation application.
- The maintenance requirements of the monitoring solution shall be minimal, lasting for 5 years between substation visits. This includes the lifetime of any battery power supply. The frequency of maintenance visits should be aligned with internal procedure documentation.
- The equipment shall be capable of remote software updates.
- Notifications shall be sent if there is a fault in the operation of the monitoring equipment, for example, if data is not being received. Where the equipment is battery operated, there shall be notification of low battery levels so that site visits can be planned.

The back-end architecture supporting the monitoring system is an important specification decision. To implement the Celsius BAU process into the ENWL network, there are several options for the back-end architecture. These are listed in Table 1 below, with an indication of the pros and cons for each.

Option	Pros	Cons
Use ENWL RTUs to pass the data into the SCADA system and develop a module to regularly process and produce required results.	Known ENWL equipment Established and secure ENWL SCADA and data processes Allows easy integration of notifications to trigger in short (near real time) timescales.	RTUs are not present at 70% of sites, and the cost of installing at a non-RTU site might negate the Celsius business case Potentially significant task to integrate a Celsius rating module
Use a virtual RTU in the form of a mobile connection to ihost to pass the data into the SCADA system and develop a module to regularly process and produce required results.	Known ENWL equipment Established and secure ENWL SCADA and data processes Allows easy integration of notifications to trigger in short timescales. May be lower cost than a full RTU	Costs of this option need investigating. Potentially significant task to integrate a Celsius rating module Restricted in the choice of BAU monitoring solution.
Use an independent monitoring and SCADA with the required module to produce the results, which are then passed into the asset records (manually in the short term, and then via an Application Program Interface (API) later)	More market choice of monitoring and processing solution Freer to tailor the Celsius rating calculation module	Not part of the established and secure ENWL SCADA process (note: this may not be considered system critical data, so the level of security needed might be lower) The timescales of notifications will be limited by the communications and integration with ENWL systems. For example, notifications may be sent within a day

The monitoring data will be used to establish notifications to be sent to key ENWL personnel. For example, notifications could be developed for high temperatures or significant change in demand. Notifications shall be communicated in a useful format, for example email or SMS, and should include actionable information such as instructions for inspections and suggestions for interventions.

In addition to the above, processes and authorisations within ENWL will need to be observed; any new equipment would go through network commissioning testing to ensure that it is fit for purpose and is suitable for installation on the network. Any relevant policy documentation will need to be complied with.

5 Further work

The Celsius project ends in March 2020. There is some further work to finalise the BAU Celsius process to ensure it is ready for implementation. This includes:

- **Celsius rating method** – The detailed method for establishing the Celsius rating methods, both under continuous operation and initial estimate procedures, needs to be specified.
- **Requirement for voltage measurement** – Investigate the requirement for voltage monitoring to determine the transformer load. A Celsius rating calculated with three phase measured voltage will be more accurate. However, removing the need for some or all of the voltage monitoring would allow lower cost monitoring and a simpler installation process.
- **Disseminate Celsius processes and identify way forward** – Dissemination of the Celsius BAU process will enable further discussion of the details. Further developments can be made to the process in this document.
- **Identify a way forward**

Once the Celsius project has concluded, there is further work that is recommended to take place, including:

- **Celsius rating validation** – Further investigations to validate the Celsius rating process in a wider range of sites, including outdoor and GRP sites. This will support the implantation of the Celsius methods, and learning could be incorporated as it develops.
- **Review of inspection frequency of Celsius sites** – Potential reduction in inspection frequency of Celsius sites, supported by increased remote data and visibility, would reduce network costs.
- **Further uses for Celsius data** – Investigations into further uses for Celsius data, particularly when a wide range of sites are being monitored.

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