WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

DEDUCE
Low Cost Sensors – Competition Report

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1 Executive Summary

Recent growth in embedded generation such as wind and solar photovoltaic (PV) systems and the anticipated consumer uptake of electric vehicles (EVs) and heat pumps present new challenges for Western Power Distribution (WPD) to develop and operate its network which will experience greater fluctuation in electricity demand.

Data from maximum demand indicators in distribution substations is inadequate to understand the spread of demand over time. Retro-fit datalogging solutions are available for substation monitoring, but cost typically >£1200, which would be difficult to justify for all of WPDs 40,000 distribution substations.

This NIA (Network Innovation Allowance) research project on network analogues was conducted by CREST (Centre for Renewable Energy Systems Technology at Loughborough University in conjunction with Aston University and WPD.

The aim of the project was to identify and develop a novel low-cost monitoring approach with a target cost of £100 per substation.

Engineering projects usually capture the requirements first then identify the best solutions for those requirements. This project intentionally has a tightly defined cost requirement and loose technical requirements, which are as follows:

- The solution shall cost £100 or less excluding installation and operation costs.
- The solution should give an indication of substation loading.
- The solution should act as a replacement for existing MDIs (maximum demand indicator).
- The solution should provide as many channels of useful data at the highest feasible resolution within the cost requirement.
- The solution should consider how data will be transferred to a WPD datacentre or control room.

This report focuses on the setting up and running of a student competition designed to investigate this as a technique for encouraging innovation. The competition ran as a two stage process with ideas submitted on paper and then shortlisted teams provided a hardware budget to prototype their system. Key learning points are as follows;

1. Timing is crucial to running a student based competition. Missing the key windows of opportunity could mean reduced numbers of competition entrants.
2. Once shortlisted, the students worked hard to produce hardware and showed an excellent level of commitment to the competition.
3. The competition came up with some interesting ideas, but none that met the full brief and are worth pursuing at this time.

2 Introduction

2.1 Background

DNOs currently have very limited visibility of LV networks. With Supervisory Control and Data Acquisition (SCADA) systems generally limited to 11kV feeders, visibility of LV network loading is restricted to Maximum Demand Indicators (MDI). These manual readings are generally supplemented with industry metering flows to develop an understanding of network loading. MDIs are restricted by their need to be reset periodically as well as the potential for network back-feeds to distort readings.

A number of previous LCNF projects have looked into LV monitoring. This has pushed the market for LV monitoring forward significantly from the custom built units used for the Low Voltage Network Templates project, to a number of commercially available units available to date. WPD currently has Standard Techniques (STs) for the installation of ground mounted and overhead monitoring as well as a fully tendered framework agreement for the supply of such units.

These units depend primarily on the measurement of voltage and current to determine loading. Voltage is generally measured directly through the use of busbar clamps or modified fuse holders with a voltage take off point. Current is generally measured using Rogoswki coils. These units are capable of measuring the detailed loading of each phase on each feeder and provide a significant level of detail and granularity. However, these devices are also costly due to the requirement for multiple sensors. This has limited their roll out to date.

This project looks to develop a low cost (sub £100) distribution substation monitor based on indirect loading measures (temperature, noise, vibration…). At a minimum this must give access to more granular and less error prone data than is currently acquired through MDIs. The substation monitor is expected to develop a methodology for the acquisition of basic whole substation loading profiles as well as the optimal method for the delivery of such data to planning teams and simplicity of installation.

To meet these aims the following approaches were proposed:

- Investigate existing low cost sensors that can be used for indirect substation loading monitoring.
- Investigate new disruptive technologies to determine their suitability and accuracy for monitoring
- To use existing low cost measurement devices or packages (such as a smart phone or raspberry pi) to indirectly provide measurement
- To run a university based competition to enable non-traditional solutions to be explored

This document concentrates on the planning and running of a University based competition.

2.2 Scope

To run a University competition, the following processes are required;

1. Concept
2. Competition brief including promotion and IPR
3. Shortlisting
4. Providing support and guidance
5. Testing
6. Judging

These will be discussed within this report.

2.3 Presentation of learning

Throughout the document, key learning outcomes are presented in a box as follows:

LP x	Brief description of learning.

Each piece of project feedback is referenced as a uniquely numbered Learning Point (LP). All learning points are collected together in Appendix A.

3 Competition concept

This project is primarily around the concept of the development of disruptive technology. Therefore, it was considered likely that having an input into the process from as many participants as possible was likely to yield a higher level of new and interesting ideas than a small group brainstorming around a table.

There is no straightforward way of directly involving lots of academic staff and post-doctoral researchers into this process. This is because their time needs to be properly costed and accounted for. This would have resulted in the requirement to sort out many different contracts among Universities and would have been very expensive. Targeting the student body through a competition avoids this requirement. In addition, students tend to have a good level of current knowledge around the latest consumer electronics. It was felt this could be advantageous when looking for low cost sensor solutions.

Universities tend to be sub divided into common areas such as Engineering or science and within this there exist different departments such as electrical and electronic engineering. However, research teams are not always based on traditional boundaries and may cut across themes such as Energy. To be able to approach the relevant students who may be interested in such a competition, it is helpful if the competition brief is self-contained within a department as is it easier to find key personnel with whom to pass publicity materials and information.

LP 1	When developing competition concepts, it is easier to plan a competition and target groups of researchers if the competition is within a common and traditional research theme for which large University groups exist. Targeting students across different research themes is more difficult.

Running University based competitions is not a new idea. There are a small number of such competitions run in the UK. One such competition is "The Future Power Challenge" which ran last year for the first time and on the strength of its success is re-running again this year. This competition is funded by Industry and heavily promoted through the EPSRC funded Power Electronics Centre. The main entrants tended to be researchers at large power electronic based groups (Imperial, Bristol, Bath, Nottingham and Cambridge). The competition was run as a group-based activity and needed to include at least 1 researcher and 1 PhD student within the team. The level of knowledge required to pull together a project in this area was highly specialised and would not have been appropriate for undergraduates. Within the field of Power Systems and sensors the area of research activity is not so structured and there are not large UK groups which cover both areas. This means knowledge around the area tends to be more scattered and less easy to target.

Having decided to run a University based competition, it was necessary to define the structure and rules of such a competition. The competition was developed around a two-stage process where only hardware of the most likely entrants to succeed can be funded. Limiting this to 8 teams/individuals and providing sufficient income to allow several prototypes to be built, maximises success.

The future power challenge competition did not provide funding for prototyping. However, they targeted very large and established research groups which had access to money to enable this prototyping activity to be covered. The competition was backed by industry which already funded those groups and therefore there was incentive for those research groups to self-fund the projects to keep good relationships with their funders. The competition in this case is different as WPD does not have long term funding relationships with groups of Universities at the same level and therefore the willingness to self fund hardware prototypes does not exist.

LP 2	If the competition is based within a large group – funding for hardware prototypes does not need to be provided or is restricted to key groups. If funding needs to be provided for hardware this complicates the competition (everyone who enters gets funding? Only some competitors?)

LP 3	For a two-stage competition, it is useful to keep the first stage entry as easy as possible to include as many different ideas as is possible. Requirements for detailed drawings and part lists would put off entrants of interesting out of the box based ideas.

By not specifying the number of entrants in a team it allows a wide range of possible entrants. This can include, for example:

- Individuals working on a course related student project which can then be submitted as part of their degree or as part of a team
- Individuals undertaking research into a PhD
- Doctoral Training students undertaking a group project
- Groups of friends looking for something to do in their spare time

LP 4	It is useful to loosely specify the number of people in a team

4 Competition brief

The competition brief (included in the Appendix) included a technical description and some photos of substations, along with a summary of why WPD were keen to develop low cost sensors and some terms and conditions.

The description of the competition in the initial publicity material was intentionally loose for two reasons. Firstly, to widen the potential pool of applicants. Secondly to encourage entrants to be imaginative in their approach and not be heavily constrained by existing approaches. It was also decided that it wasn't essential to prescribe every detail of the competition format and requirements in the beginning, but, allow it to evolve in response to initial feedback from entrants and academics.

LP 5	It is useful to loosely specify the competition brief to encourage entries from a wider range of backgrounds

For example, the competition brief was intentionally loose as to whether the entries needed to include datalogging and the means of transmission. Some approaches might inherently include an analogue-digital (AD) circuit, processor, memory and a radio modem (for example using a smartphone), whereas for entrants with very novel sensing approaches which required considerable work on signal processing, to also design the datalogger and transmissions functions would be a distraction from the actual sensing where datalogging and transmission could be added using low cost modules later.

LP 6	If the competition is loosely specified it is necessary to include a statement in the terms and conditions of the project which allow modifications at a later date (even if not required).

4.1 Promotion

The timing of the competition promotional material was considered to be important to the success of the competition. Materials ideally should reach students just before they pick projects, so they can be guided towards this as an idea. Final year students often have meetings with supervisors in the first or second week of term where they would need to decide the broad theme of their project in order to start on background research.
The start of term varies between Universities, in 2017 Autumn term started on the 2nd October at Loughborough, 18th September at Manchester, 11th September at Strathclyde, 3rd October at Cambridge, 23rd September at Bath. The contract for this project was formally signed on the 3rd November, approximately 4 months from initial concept discussions between CREST and WPD in early August.

LP 7	It is helpful if competition dates can be tied to common undergraduate University dates: • Initial launch before students are picking projects • First stage entry after term 1 exams and before the student gets too busy with project work • Second stage entry after exams and before the student leaves the University (while waiting for results) This is not so critical for researchers who operate on more flexible timescales but are often tied to specific projects.

LP 8	It is helpful to factor in the time necessary to sort our project contracts so that this doesn't impact key dates.

LP 9	A wide range of different promotional tactics need to be used to try and target as many potential entrants as possible.

The competition was launched with a multimedia publicity campaign, including a bespoke website, posters, Facebook as described below.

The following competition website was setup:
www.lboro.ac.uk/research/crest/research/networkssystems/uk-universities-student-sensor-competition.html
shortened to tinyurl.com/sensor-comp also a QR code was used in marketing material as shown in Figure 1.

Figure 1: QR code 2D barcode used for the competition website

The main feedback from academics at other institutions was that they had already allocated student projects when they heard about the competition. Final year projects tend to be allocated in the first weeks of the autumn term or in the final weeks of the preceding summer term.

LP 10	Student competitions need to be disseminated to academics well in advance of the start of term so they can incorporate them into final year projects.

Awareness is a key factor and many student and academics hadn't heard about the competition until close to the first deadline, so there is advantage to running a competition

as part of a regular annual event, so academics can plan ahead for the next upcoming competition, and future competitions are publicised by the award publicity from preceding competitions.

LP 11	Student competitions accumulate awareness amongst students and academics if they operate as a regular annual event.

A forum was also setup for discussion about the competition, firstly to minimise email traffic, and secondly so that information given to any entrant would also be disseminated to all other entrants for fairness. Facebook was used as a quick platform for the forum which is generally popular with students

www.facebook.com/groups/sensor.comp/.

Not all students use Facebook and future improvements could include the use of other forums such as LinkedIn. An additional benefit of the Facebook group is that most students include their place of study in their profile, so it has been a useful tool to see where publicity is reaching students.

The key media channels needed to be set up prior to competition launch so that students looking for more information could go directly to other sources on multi-media. It was quick to set up a Facebook page but much more time consuming to design and pull together a bespoke website. It was also time consuming to pull together printed material and this was sent out after the launch.

LP 12	The marketing strategy should consider that whilst social media channels are generally fast to setup, print media and new websites take longer.

The Facebook group was updated at least once a week with useful information such as competition updates and substation component specifications. The rate at which students joined the Facebook group was high at the beginning of term but quickly dropped off.

Experience in other areas such as asking for student volunteers to undertake outreach activity and helping with open days shows that students tend to have more free time and to be helpful when their work load is low.

LP 13	Students are more receptive to additional activities at the start of the academic year before workload and exam anxiety build up.

A wide range of promotion channels was used to hedge against the limitations for individual channels.

- An email sent to 120 academics at 60 institutions identified from the following sources:
    - IET (institute of Engineering and Technology) Power Academy partners

  - Engineering degrees accredited by the IET for Chartered Engineer status.
  - Attendees at the 2017 Low carbon networks and Innovation (LCNI) conference
  - Academics with an interest in WPD project Falcon
  - Personal contacts of Project staff

  The complete list of Universities approached is given in the appendices.
- Leaflets and posters sent to the above institutions.
- Adverts on various University websites and social media channels –
- CREST website: www.lboro.ac.uk/research/crest/news/news/sensor-competition.html
- CREST facebook group: www.facebook.com/CREST.lboro/
- CREST LinkedIn :www.linkedin.com/groups/2522195
- CREST Twitter feed : https://mobile.twitter.com/crestsheryl
- IET student communities : https://communities.theiet.org/communities/discussions/viewtopic/335/411/22483?post_id=107460#p107460
- Engineering at Loughborough Facebook group (13th November): https://www.facebook.com/LboroEng/?hc_ref=ARS3FS6vu_gSP8MUx8QlKgNFTuZWBIijb9ftSCZ8jv0knyv7FZ71f9CyhbqX1AaWScU&fref=nf
- Other Universities which advertised the competition on their news pages (no longer visible)

  Heriot Watt University:
  www.energy.hw.ac.uk/news/uk-universities-student-sensor-competition.html
  Nottingham University:
  www.powerelectronics.ac.uk/documents/crest-wpd-sensor-comp-detailsrules.pdf
- Adverts on display screens in University premises.
- A Mailout to all Loughborough University Engineering Students.
- Leaflets given out at Loughborough University careers fairs.
- Messages placed on student social media groups by students working as careers and publicity interns.
- A 16:9 electronic poster displayed on screens in the engineering departments at Cardiff University and Loughborough University.
- Universities were offered a presentation given to students about the project.

LP 14	To keep interest among students (for whom we have no access to mailing lists) it is necessary to maintain contact with key University staff to help with distributing publicity material and providing timely prompts.

Publicising via email was a particular challenge for two reasons. Firstly, lists of email addresses become out of date quickly as people move jobs. Secondly, academics suffer email fatigue as they often receive hundreds of emails per day and tend to delete any that aren't personally addressed to them. Correspondence was also sent to departmental administrators to mitigate these risks.

LP 15	Databases of university contacts need to be regularly updated with new sources, to compensate for people moving jobs

The initial email with electronics documents sent to academics received no replies, but resulted in several students joining the Facebook group.

LP 16	Random follow up checking to check coverage and success of promotion is a useful and informative task

Random checks through contact with academics revealed that some had embraced the idea and forwarded to students whilst others had ignored and deleted from the in-box. Follow on leaflets were therefore sent to administrative staff who act as an alternative to individual academics and are more likely to distribute material on notice boards.

LP 17	Setting up a competition website allows students to follow up on leaflets distributed round their university and allows an additional form of follow up

A postal letter with hardcopy flyers resulted in one reply from a departmental administrator with request for an electronic copy to display on screens in corridors. The second email sent to academics received the best response with 5 replies from 5 institutions. The relative success of the second email was thought to be because of the offer of presentations.

- The presentation being offered was framed as a general presentation about the project in addition to being about the student competition, this resulted in being offered slots in departments regular seminar series.

LP 18	Emails sent to lists should be very concise, so a skim reader would get directly to what was on offer (before they have deleted them).

LP 19	Emails are more likely to be acted on or replied to if they offer something tangible and beneficial to the recipient.

LP 20	Giving presentations at institutions as part of their seminar series is a good way to reach and engage with both students and academics, however these are booked up many months in advance and are dormant during exam periods so require considerable advance planning.

The universities in the circulation list were contacted to offer a short presentation about the project and the competition, the response was better than more general emails about the

competition and a number of institutions offered appointments either as ad-hoc talks as part of taught modules or as part of their research seminar series. However, in the case of taught programmes, scheduling is challenging since the talk has to fit in with the teaching calendar. In the case of research seminars the challenge is that these are often booked up months in advance. The tour presentation is included in the appendices.

The following questions had been received from students pre first stage submission deadline:

- Are group entries allowed
- What transmission rate is required
- What is the specification of the transformer

4.2 Intellectual property

Ofgem NIA rules require that-

"All other Network Licensees will have the automatic right to use Relevant Foreground IPR for use within their network system royalty free. The Network Licensee will ensure that arrangements are in place to allow such access. "

A clause to this effect was included in the competition rules. Discussion with an IPR officer at Loughborough highlighted that IPR generated by research students is generally owned by their host institution, whereas undergraduate IPR is generally owned by the student, for this reason the following clauses were included in the competition rules.

- Post graduate researchers should confirm that their University allows entry under their IP policy before applying
- Competitors shall notify Loughborough University and WPD if they subsequently commercialise their idea

LP 21	IPR requirements of Universities are often at odds with industry. Most IPR issues with staff have to go through legal teams as part of the permission process for submission. To avoid such issues with students – it is useful to point the students at the Ofgem rules and ensure they are responsible for meeting their University requirements (ie talking to their legal teams prior to submission) rather than pre-determining this in advance as it is not possible to guarantee permission for entry from every University approached before competition release.

LP 22	IPR issues tend to be less restrictive for Undergraduates than PhD students. PhD students work is "owned" by the University and they are less happy for this to be given away. Therefore, targeting undergraduates from an IPR perspective is preferable. Postgraduates tend to have more knowledge, so it is good not to exclude them due to IPR issues.

LP 23	When writing the rules for any future student competition, the rules should consider how to marry the IP requirements of the project funders/sponsors and the IP rules of the students' host institutions.

5 Shortlisting

Entries were received from the following universities:

- Cardiff
- Liverpool
- Liverpool John Moores
- Loughborough
- Sussex

Of the entries, 40% had joined the Facebook group and 80% had emailed beforehand with questions about the competition. 20% entrants had no prior communication before submitting.

The competition brief was intentionally written to in a way which accurately describes the main components of a distribution substation without describing current monitoring options. Whilst the competition was titled the student sensor competition, the brief didn't specify whether the entrants should focus on the actual sensor or the signal processing and transmission or if they had to deliver a complete system. All the entrants interpreted the brief by proposing a complete system, but different entrants focused on different parts of the system in terms of novelty.

Of the entries received, some of the competitors used off the shelf sensors including CTs but focused on value engineering the signal and data processing and forward communications. Some applicants took existing sensor technologies but proposed modified or value engineered variants of them.

Some entries used bespoke analogue or digital signal processing options. Most entrants used off the shelf microprocessor development boards for some or all of the A-D, control and communications. Development boards proposed included Arduino, Particle.IO, Raspberry PI and Seeduino.

A variety of communications options were proposed including GPRS, WLAN, Zigbee and Powerline communications.

The judges had questions regarding most of the entries, these were sent to the entrants by email for clarification before the final shortlisting decision was made.

Each entry was scored out of 10 against the following eight criteria:

- Background research
- Attention to detail

- Sensor novelty
- Sensor feasibility
- Signal-Data novelty
- Signal-data feasibility
- Communications novelty
- Communications feasibility

Therefore, the maximum possible total score was 80,

There was considerable variation in how generous the judges were in their scoring, with average scores awarded by a judge varying from 23 to 39.
The aggregate scores of the entries varied from 24 to 40.

The development grant was awarded to all successful entries which achieved an aggregate score above 30. It was made clear to those candidates that unless they had hardware available for testing at Loughborough that they would be ineligible to win a prize.

The majority of shortlisted ideas were final year student projects with the remainder PhD teams.

6 Support and Guidance

The shortlisted students were spread over different Universities and each was offered the support of a member of the CREST team along with an open invitation to visit Loughborough. Only one team came to Loughborough prior to testing to discuss their project.

LP 24	It was useful to meet with students prior to competition submission and testing to understand what was required from a testing perspective. As the scope of the project was so wide, the test requirements for the teams were very different.

On the whole, the students were content to work independently (or with a supervisor at their own institution). As the deadline approached for hardware testing, the students were prompted with an email about bringing their hardware to test and arrangements were made for train journeys and hotel accommodation as required.

The students also filled out a questionnaire so that the University could take feedback on the level of support offered and to understand if the students felt any other support was required. The students were asked;

1. How did you find out about the competition?
2. Did you feel that a two stage process worked well for you?
3. How did the timings and deadlines work? Were you pushed for time at any stage?
4. Did you feel the hardware budget for stage 2 was sufficient?

5. Were there any ways in which Loughborough could have offered more support?
6. Were there any ways in which WPD could have offered more support?
7. Were there any aspects of the competition you would change for next year?
8. Have you any other comments that you feel would be helpful for future competitions?

LP 25	Gathering feedback from students is a useful way of improving the process for any follow on competitions.

Comments back from the questionnaire are varied and include;

- The majority of students found out about the competition through word of mouth, which made them more aware of the advertising material. One group found out by a displayed poster.
- Timing worked ok with the academic timetable and didn't interfere with exams and coursework.
- Most students liked the two stage process with one team feeling that getting through the first stage made them more committed to seeing the project through to the end.
- Some students would have liked more time for hardware design and development (perhaps by shortlisting earlier)
- A hardware budget of £500 was considered by all to be fine and allowed the students to explore different options while developing their sensors
- Support offered by both Loughborough and WPD was considered to be good
- Some students would have liked access to off-service real equipment to help with testing
- If the competition were to be re-run then one group have suggested including an example case study.

7 Testing

The students visited Loughborough over a two week period to undertake testing of their hardware. During this time two members of Loughborough personnel were available at all times the students were around to help supervise, mentor, support, set up measurement devices, adjust the test rig as required and witness the testing program.

The testing for each of the shortlisted teams was individual to their requirements and so the test rig and instrumentation required was unique in each case.

LP 26	It was necessary to provide intensive support on the day of testing to modify test rigs and deal with instrumentation to allow witness testing of the hardware. As each student had been developing their solution at different Universities the test facilities that each had access to was slightly different.

LP 27	It was very obvious on the days of testing that the students were committed and spent much time and effort on getting their hardware working properly. There was a minimum amount of adjustment to their hardware to allow it to work with our test equipment.

LP 28	The effort, knowledge and commitment of all the students was impressive and it was felt that this could provide an excellent opportunity for identifying good future employees.

Figure 2 to Figure 4 show a selection of images of some of the hardware that was tested at Loughborough. As the hardware was different for each entry it was necessary to adapt the rigs. To enable testing of all solutions the following test equipment was required.

1. The Loughborough test rig with single core cable to test loading and additional cabling required to give a measure of voltage at the primary of the transformer
2. A variac connected to a single core cable to test voltage measurements
3. An oscilloscope to look at waveforms with both current and voltage probes. It was necessary to have data capture capability as this was used to check the results
4. A multi-meter to measure voltage
5. Additional PCB based power supplies (some entrants had batteries as part of their set-up)

The entries include solutions around novel powerline communication, current testing using low cost Rogowski coils and voltage testing without contact using capacitor charging and discharging.

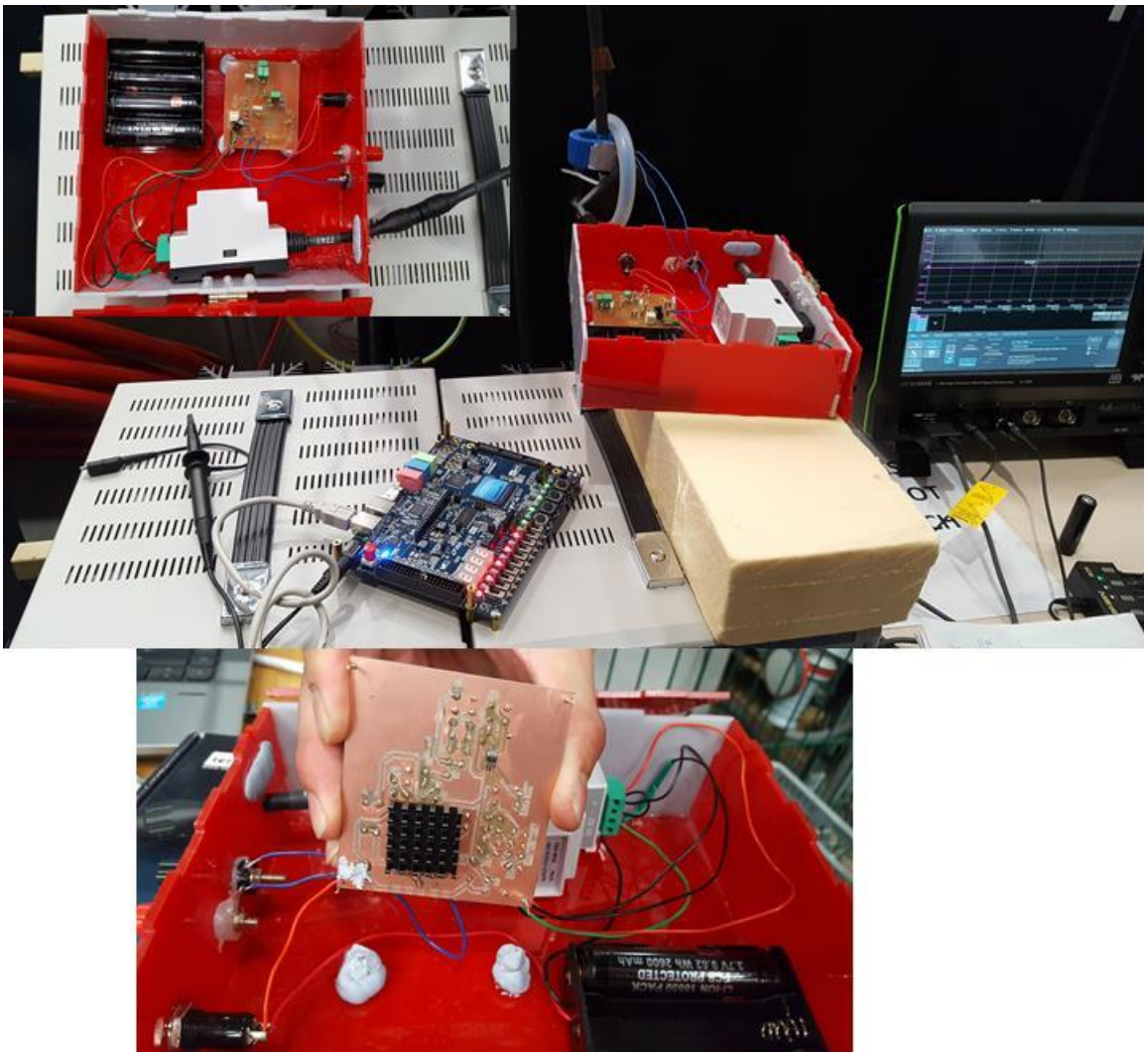

Figure 2: Images of the hardware tested on the day from the winning entry

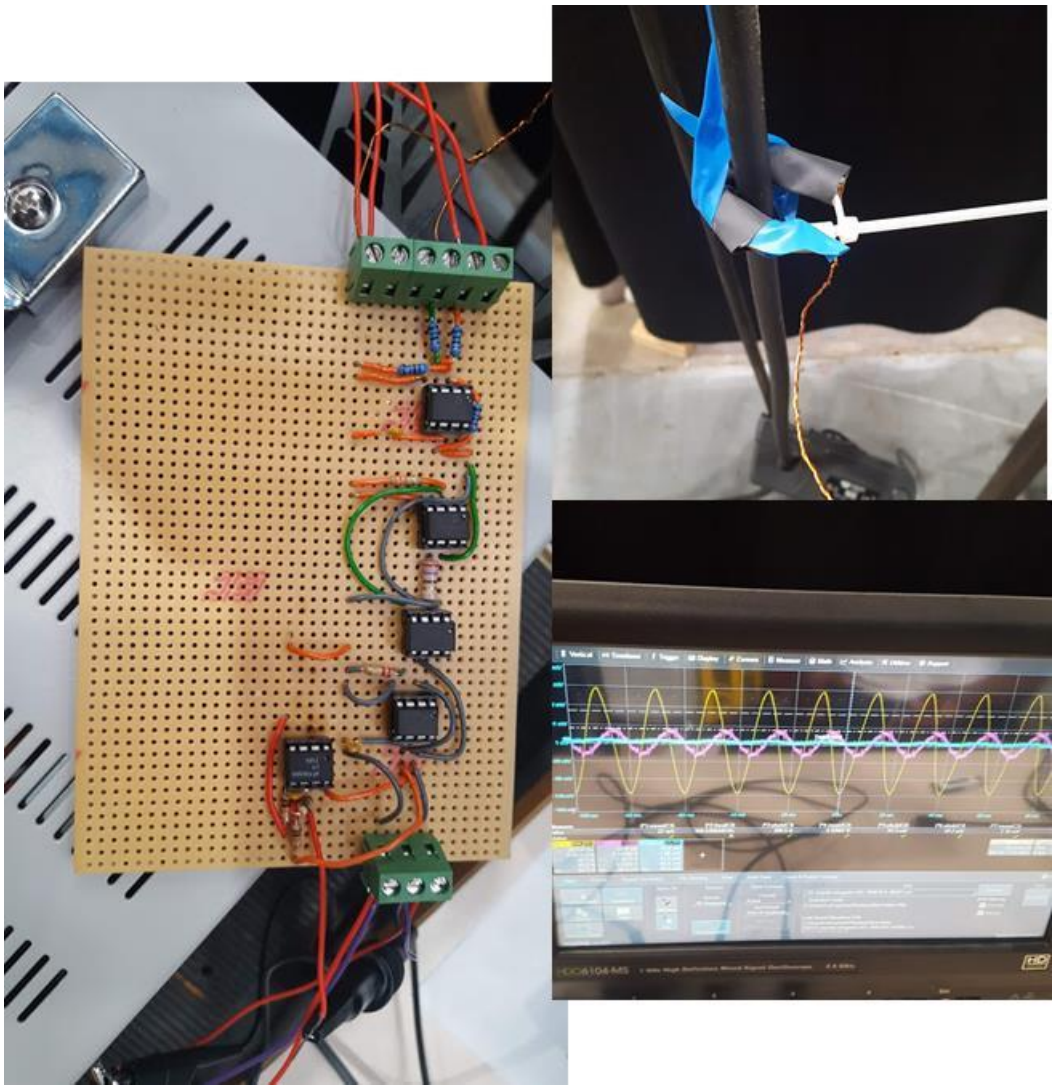

Figure 3: Images of the hardware tested on the day from the 2nd place entry

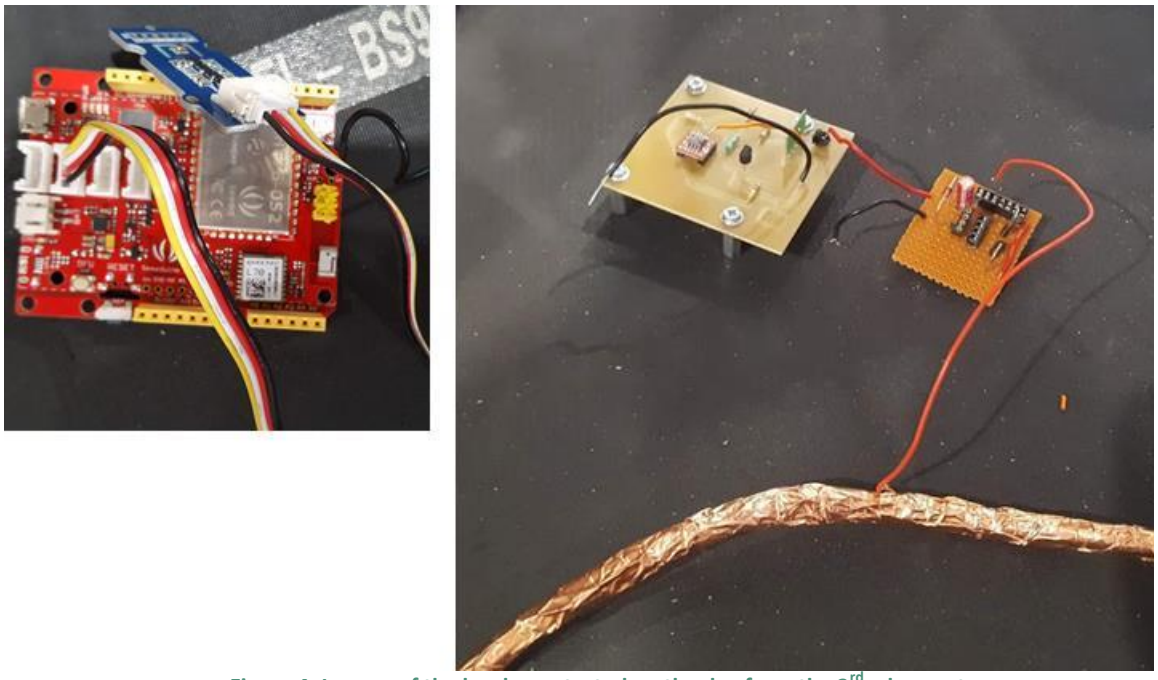

Figure 4: Images of the hardware tested on the day from the 3rd place entry

All of the entries were tested such that the variable under measurement was varied and the response was noted. Loughborough University witnessed each of the testing. Figure 5 shows a sub set of the results of the testing on the day. In most cases it can be seen that there is a relationship between the measured value and the response and that this is singular such that a value of response may be related back to the measured value. For most of the teams this was not quantified at this time and the measurement device would likely require on-site calibration to produce a look up table.

Other key points to note from the day;

1. Not all the solutions focussed on load measurement
2. None of the solutions were available as a complete solution; for example the use of power supplies, batteries which would need re-charge or intermediate data capture
3. All the solutions had bespoke electronic circuits manufactured on pcb or breadboard
4. A lot of work had gone into developing and manufacturing the prototypes
5. All of the prototype solutions worked with varying degrees of success
6. All of the solutions worked on single core cables and none would have been transferable to three core cables in their current state.
7. Most of the solutions would have worked with screened and earthed cable, but one solution required the cable to have no screen.
8. The costs provided by most teams were lacking key pieces of information as to a total package solution as they focused on the part of their sensor that was relevant.

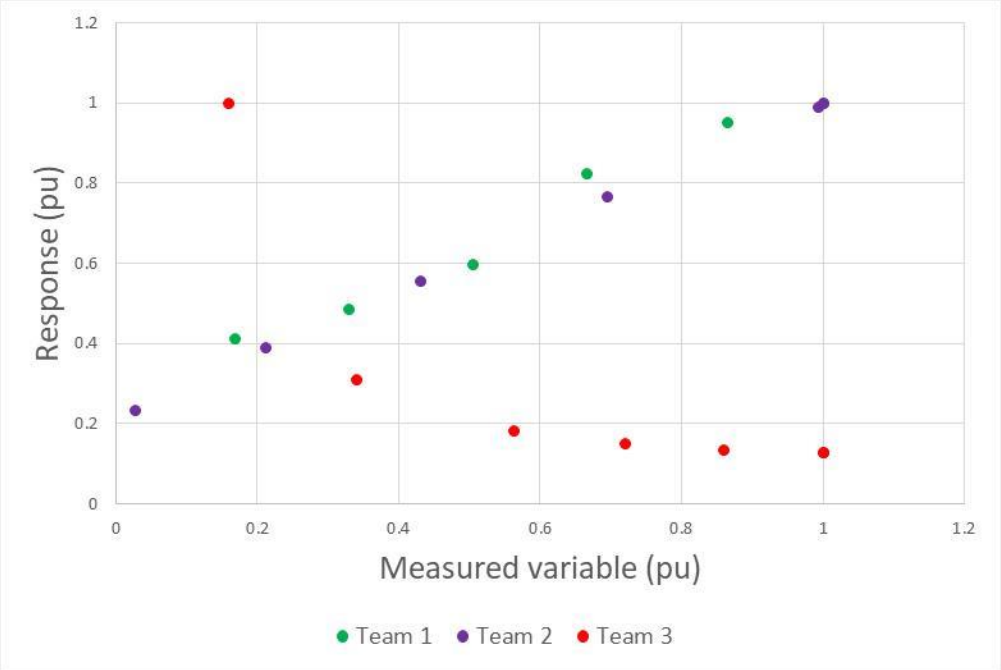

Figure 5: A sub-section of the witness test results normalised for measurement

8 Judging

Judging was undertaken solely by WPD staff to avoid any bias.

To help with judging each of the teams produced a slide show explaining their solution and some cost figures. A marking sheet was also produced from which to judge the competition. This is included in the Appendix. It was decided not to share this with the teams in advance so as to avoid distracting them from their sensor development.

LP 29	It would have been difficult to arrange for WPD to be present over the two weeks of testing to witness the testing fully. Setting a fixed date for testing well in advance would have been better to allow the presence of the judges.

9 Conclusions and recommendations

It took a significant amount of effort to run a University based competition and there were issues with timings, ensuring IPR was adequately dealt with and the ability to easily target students.

Entry numbers were lower than expected. However, what was lacking in quantity was present in commitment. In particular, the student teams that were shortlisted worked hard and produced working hardware that provided measurements of potential value.

A University competition is a good mechanism for identifying knowledgeable and committed students from a recruitment perspective, but the ideas were not sufficiently developed to have value of the WPD Network at this time and would require considerable effort before they were ready as a low cost product for field trials on a grid.

10 Appendix A : Summary of Learning Points

Summary of learning points

LP1	When developing competition concepts, it is easier to plan a competition and target groups of researchers if the competition is within a common and traditional research theme for which large University groups exist. Targeting students across different research themes is more difficult.
LP2	If the competition is based within a large group – funding for hardware prototypes does not need to be provided or is restricted to key groups. If funding needs to be provided for hardware this complicates the competition (everyone who enters gets funding? Only some competitors?)
LP3	For a two-stage competition, it is useful to keep the first stage entry as easy as possible to include as many different ideas as is possible. Requirements for detailed drawings and part lists would put off entrants of interesting out of the box based ideas.
LP4	It is useful to loosely specify the number of people in a team
LP5	It is useful to loosely specify the competition brief to encourage entries from a wider range of backgrounds
LP6	If the competition is loosely specified it is necessary to include a statement in the terms and conditions of the project which allow modifications at a later date (even if not required).
LP7	It is helpful if competition dates can be tied to common undergraduate University dates: • Initial launch close to when students are picking projects • First stage entry after term 1 exams and before the student gets too busy with project work • Second stage entry after exams and before the student leaves the University (while waiting for results) This is not so critical for researchers who operate on more flexible

	timescales but are often tied to specific projects.
LP8	It is helpful to factor in the time necessary to sort our project contracts so that this doesn't impact key dates.
LP9	A wide range of different promotional tactics need to be used to try and target as many potential entrants as possible.
LP10	Student competitions need to be disseminated to academics well in advance of the start of term so they can incorporate them into final year projects.
LP11	Student competitions accumulate awareness amongst students and academics if they operate as a regular annual event.
LP12	The marketing strategy should consider that whilst social media channels are generally fast to setup, print media and new websites take longer.
LP13	Students are more receptive to additional activities at the start of the academic year before workload and exam anxiety build up.
LP14	To keep interest among students (for whom we have no access to mailing lists) it is necessary to maintain contact with key University staff to help with distributing publicity material and providing timely prompts.
LP15	Databases of university contacts need to be regularly updated with new sources, to compensate for people moving jobs.
LP16	Random follow up checking to check coverage and success of promotion is a useful and informative task.
LP17	Setting up a competition website allows students to follow up on leaflets distributed round their university and allows an additional form of follow up.
LP18	Emails sent to lists should be very concise, so a skim reader would get directly to what was on offer (before they have deleted them).
LP19	Emails are more likely to be acted on or replied to if they offer something tangible and beneficial to the recipient.
LP20	Giving presentations at institutions as part of their seminar series is a good way to reach and engage with both students and academics, however these are booked up many months in advance and are dormant during exam periods so require considerable advance planning.
LP21	IPR requirements of Universities are often at odds with industry. Most IPR issues with staff have to go through legal teams as part of the permission process for submission. To avoid such issues with students – it is useful to point the students at the Ofgem rules and ensure they are responsible for meeting their University requirements (ie talking to their legal teams prior to submission) rather than pre-determining this in advance as it is not possible to guarantee permission for entry from every University approached before competition release.
LP22	IPR issues tend to be less restrictive for Undergraduates than PhD students. PhD students work is "owned" by the University and they are less happy for this to be given away. Therefore, targeting undergraduates from an IPR perspective is preferable. Postgraduates tend to have more knowledge, so it is good not to exclude them due to IPR issues.
LP23	When writing the rules for any future student competition, the rules should

	consider how to marry the IP requirements of the project funders/sponsors and the IP rules of the students' host institutions.
LP24	It was useful to meet with students prior to competition submission and testing to understand what was required from a testing perspective. As the scope of the project was so wide, the test requirements for the teams were very different.
LP25	Gathering feedback from students is a useful way of improving the process for any follow on competitions.
LP26	It was necessary to provide intensive support on the day of testing to modify test rigs and deal with instrumentation to allow witness testing of the hardware. As each student had been developing their solution at different Universities the test facilities that each had access to was slightly different.
LP27	It was very obvious on the days of testing that the students were committed and spent much time and effort on getting their hardware working properly. There was a minimum amount of adjustment to their hardware to allow it to work with our test equipment.
LP28	The effort, knowledge and commitment of all the students was impressive and it was felt that this could provide an excellent opportunity for identifying good future employees.
LP29	It would have been difficult to arrange for WPD to be present over the two weeks of testing to witness the testing fully. Setting a fixed date for testing well in advance would have been better to allow the presence of the judges.

11 Appendix B : Competition Documents

Centre for Renewable Energy Systems Technology (CREST),
Wolfson School of Mechanical, Electrical and Manufacturing Engineering

Loughborough University

UK Universities Student Sensor Competition

Are you eager to put your engineering knowledge to use? Our Student sensor competition can provide technical support to develop a new product and win a £5000 cash prize.

Technical description

Distribution Network Operators like Western Power Distribution (WPD) are responsible for the physical infrastructure which delivers electricity to end users. This involves taking in-feeds at 132kV and transforming this down to Low Voltage (LV) to connect to customers. Historically LV distribution substations have had minimal monitoring. With the connection of more Low Carbon Technologies (LCTs) such as Solar PV and Electric Vehicles, network loadings are changing. Such changes could require networks to be upgraded. Additional substation monitoring could allow for a more accurate picture of loading and enable better decisions about where upgrades are really needed. Existing monitoring technology is available but is too costly to roll out across WPDs 41,000 ground mounted distribution substations.

The objective of this competition is to develop a low-cost sensor and/or data capture device which can monitor substation loading for less than £100 and can be installed easily.

There are numerous variants of the ground mounted distribution substations which have been installed over the last 40 years, however they typically consist of the following main components (Figure 1):

1) An oil cooled 11:0.400kV Transformer
2) A disconnect link or connector
3) A 230/400V busbar
4) 2 to 7 sets of 3 fuses.
5) The single core tails of the outgoing 4 core armoured cables.

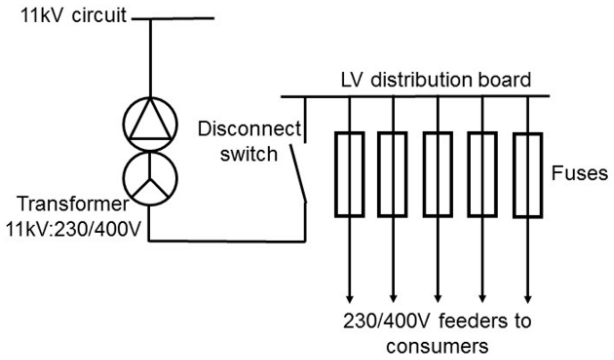

Figure 1 Simplified 1-line schematic of a distribution substation

The transformer is a sealed unit which cannot be opened. Access to the disconnector or busbar is limited. The fuses can be removed in some circumstances by closing links elsewhere in the feeder circuit; however this significantly increases installation complexity.

Figure 2 Photograph showing 11kV:230/400V oil cooled transformer

Figure 3 Photograph showing maximum demand indicators (top right), disconnector (right), rows of fuse holders with only 1 circuit (left hand circuit) fused.

The outgoing tails are accessible but cannot be disconnected. Figure 4 shows outgoing cables fitted with rogowski current sensors which can be clamped onto live cables without disconnection.

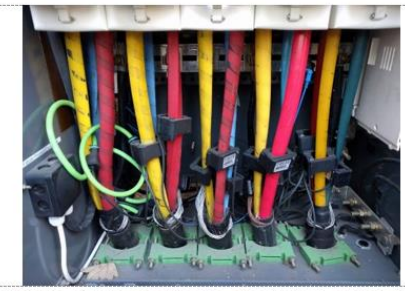

Figure 4 Photograph showing outgoing cables.

The first round of the competition is to produce a description and sketch of a low-cost method of measuring substation load.
Entrants could include cheaper methods of measuring current or voltage but may also infer loading indirectly from noise, heat, vibration, displacement, capacitance, induction, imaging, etcetera, measurements.
Distribution substations don't have fixed internet or telephone connections, so cost effective data transfer needs to be considered (potentially via mobile, radio networks or even local download).

Entries can consist of one or all of the following subsystems

1) Sensing device
2) Datalogging device
3) Communications device

More information about substations can be found on the project facebook page: https://www.facebook.com/groups/sensor.comp/

To contact the competition administrator, please email b.goss@lboro.ac.uk

Terms and Conditions

Competition objectives:

- To develop new and useful low-cost approaches to monitoring of distribution substations
- Provide development funding and technical support for shortlisted entrants to further develop their idea.
- Award prizes to the winning entrants.
- Celebrate the shortlisted candidates and winners through Loughborough University media channels

Shortlisting:

- A fully-completed entry form must be submitted by the applicant(s).
- The judges will short-list up to 8 finalists on the merits of their entry form.
- The closing date for the shortlisting entry form is 16th February 2018

The shortlisting panel will be looking for:

- How innovative is the idea?
- How financially feasible is it?
- Understanding and application of underlying physical principles
- Evidence of an understanding of the design and operation of distribution substations.
- Quality of presentation
- Accuracy of information provided in the application form

Support for shortlisted finalists:

- Entrants who pass the shortlisting will be awarded £500 of development funding to build and test a hardware prototype of their idea for submission to the second round of judging. Feedback and technical advice will be available from engineers at CREST via project surgeries hosted at Loughborough University and on https://www.facebook.com/groups/sensor.comp/

Final Award:

- The closing date for the final award entry form is 29th June 2018
- Final award prize winners will be announced on 15th July 2018

The final award panel will be looking for:

- Consistency between stated specification and verification tests
- Reliability and practicality of the concept
- Accuracy, durability and usability of the provided prototype
- Responses to Q&A session (at Loughborough or remotely)

The Prize:

- Winners of the Final award will be awarded prizes as follows:
  - 1st prize £5,000 award
  - 2nd Prize 1,000 award
  - 3rd Prize £500 award

Eligibility:

- The competition is open to all taught students registered at a UK further or higher education institutions
- You can enter as a group or individually
- The entry can be linked to a project as part of your course or research activity.
- Applicants must be currently registered as a student or have recently completed their course and are waiting to graduate.

Additional rules and information:

- Applications must be received by the deadlines
- Applicants must meet the eligibility criteria
- The judge's decision for the shortlisting and final award will be final
- Shortlisted students will need to present proof that they are a current registered student at a UK academic institution on the date of application.
- All recipients of development funding will acknowledge Loughborough University / Western Power Distribution (WPD) for example in future events/presentations etc.
- Prize winners may be expected to participate in photography and video interviews on receipt of the award.
- The UK Universities Student Sensor Competition is operated under the DEDUCE (Determining Electricity Demand Using Consumer Electronics) project by Loughborough University for Western Power Distribution.
- Competitors in the Project shall retain all rights in and to their Background Intellectual property rights (IPR) and the Relevant Foreground IPR generated.
- WPD and all other network licensees shall have a royalty free licence to the Relevant Foreground IPR arising from the competition as per Ofgem NIA rules[1]
- Post graduate researchers should confirm that their University allows entry under their IP policy before applying
- Competitors shall notify Loughborough University and WPD if they subsequently commercialise their idea
- Competitors consent for Loughborough University to publish ideas generated in the competition in the public domain in reports, publications, etcetera.
- Loughborough University retains the rights to disqualify applicants from winning if it has reasonable grounds to suspect that the applicant is in breach of the eligibility terms and conditions.
- Loughborough University reserves the right to cancel or suspend the competition or amend the rules without notice by posting changes on its website www.lboro.ac.uk/research/crest/news/news/sensor-competition
- Neither CREST, Loughborough University nor Western Power Distribution shall be liable for any loss or damage suffered by any applicant entering this competition
- *All details of the competition are subject to change at the discretion of the organisers*

12 Appendix C : Postal Flyer

Centre for Renewable Energy Systems Technology (CREST)
Loughborough University
Leicestershire LE11 3TU UK

T: +44 (0)1509 635340
E: crest@lboro.ac.uk
W: lboro.ac.uk/crest

Loughborough University

UK Universities Student Sensor Competition

Dear fellow academic,

Following on from our previous email, we would like to invite your students to compete in an all University competition we are operating in conjunction with Western Power Distribution (WPD).

We would be extremely grateful if you could post up the attached posters where they'd be seen by your students.

The aim of the competition is to develop unconventional low-cost methods of measuring and recording power demand on electricity distribution substations. The competition is a two-stage process, initially a paper based application with a design concept and then short-listed candidates will be invited to build a hardware prototype for experimental validation. Shortlisted entrants will receive £500 development funding and support from CREST engineers. Competition winners will receive cash prizes and publicity for their idea.

We are happy to accept competition applications based around individual projects (BEng, MEng, MSc) PhD thesis or even coursework related projects. Entries from both individuals and groups are welcome and we welcome entries from any technical discipline. If you have a cohort of students who would be interested in the competition, we would be happy to organise an on-campus presentation for your students with question & answer session to address specific questions.

We have set a shortlisting deadline of 16th February 2018 to minimise clashes with exams, likewise the deadline for the final submission would be 29th June 2018. If you have any questions or feedback, please don't hesitate to get in touch.

Detailed information, rules and an entry form are available from:
tinyurl.com/sensor-comp or facebook.com/groups/sensor.comp/
or by email: b.goss@lboro.ac.uk

Many thanks for your consideration and support,
Brian Goss and Dani Strickland

UK Universities Student Sensor Competition

Are you eager to put your engineering knowledge to use?

Our Student sensor competition can provide technical support to develop a new product and win a £5000 cash prize.

Electricity network operators like Western Power Distribution need more network data to cope with new challenges like electric vehicle charging. Existing monitoring systems are too expensive to use widely.

The aim of this competition is to develop new approaches to substation monitoring.

Entries may be entirely new methods of measuring and recording substation condition or use existing devices in new ways, but must show novelty beyond what is currently available.

The competition is open to all taught students studying at UK universities. The closing date for shortlisting of concepts is **16th February 2018** and for the final award is **29th June 2018.**

The UK Universities Student Sensor Competition is operated under the DEDUCE (Determining Electricity Demand Using Consumer Electronics) project by Loughborough University for Western Power Distribution.

For detailed competition advice, rules and an entry form, please visit:

www.lboro.ac.uk/research/crest/news/news/sensor-competition

Loughborough University
Centre for Renewable Energy Systems Technology

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

13 Appendix D – Judging Criteria

Please mark 0-5 where 5 is very relevant and 0 is not relevant

Main Objectives	
To develop new and low cost approaches to monitoring substations	
Shortlisting objectives	
Background research	
Attention to detail	
Sensor novelty	
Sensor feasibility	
Communications novelty	
Communications feasibility	
Prototype objectives	
Level of hardware development	
Deduction of load (or other) from hardware	
Accuracy	
Linearity	
Practical installation	
Practical usage	
Likelihood of further development	
Other	
Engagement of team	
Usefulness of documentation produced	
Cost of product	