Institution: Brunel University London		
Unit of Assessment: 12 Engineering		
Title of case study: Capacitively coupled cables for transmission and distribution of electrical power		
Period when the underpinning research was undertaken: October 2017 – March 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Mohamed Darwish	**Role(s) (e.g. job title):** Senior Lecturer	**Period(s) employed by submitting HEI:** 08/1983-present
Period when the claimed impact occurred: 2017-Dec 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Brunel University London has worked with Enertechnos to research, develop and commercialise a new Capacitive Transfer System (CTS) cable which reduces energy loss by between 10% and 20%. The cable can be manufactured, installed and maintained with existing equipment. It also requires less infrastructure, such as booster stations, reducing the capital cost of projects by up to 40%. As a result of Brunel's research Enertechnos has revised its company strategy, grown its staff from four to fourteen, substantially strengthened its patent portfolio and secured further investment. It has also developed in-house technical capabilities to model and deliver solutions to its customers, making use of a bespoke multilevel invertor developed by Brunel to simulate long lengths of CTS cable. The company has an agreement to oversee the delivery and installation of 15 miles of cable to Western Power Distribution as part of a programme of delivery across its 4 networks. It has sold a commercial licence for manufacture in Europe for GBP250,000 per annum and is on track to sell a further 4 licences to international manufacturers. The CEO has been able to influence both UK public policy on electricity pricing as well as at US Energy Industry events with an invitation from American Electric Power.

2. Underpinning research (indicative maximum 500 words)

In the UK, the present network of transmission cables used to distribute energy from power generators to loads is faced with a number of challenges that are exacerbated by the move to bring more renewable energy to the grid. The research of Dr Mohamed Darwish at Brunel University London [1] on Capacitive Transfer System (CTS) cable has addressed two of the major challenges and enabled Enertechnos to bring new products to the market.

One challenge is the fluctuation of power along cables - for example, when renewable energy generators such as wind farms work are at the upper limit of power generation, there is a voltage drop at the receiving end due to high load current (power loss). Conversely, when the power load is low, there is a voltage rise at the receiving end (the Ferranti effect). These phenomena are further pronounced when the length of the cable increases. Series capacitors have been successfully used to enhance stability of high transmission networks, however these are expensive devices. [2].

While maintaining a similarity to conventional cables, Dr Darwish's team re-designed the CTS cable by conducting multi-physics simulations including electric, magnetic and thermal finite element analysis to simulate the various designs of CTS cable to deliver the best prototypes for testing.

The re-designed multi-layer cables increase the conductive area in the wires by increasing the dielectric layers between input and output wires. These additional dielectric layers balance the main conductor inductance. The result is that CTS cables deliver increased power and reduced line voltage drop of between 10% and 20% when delivering the same load current because it is able to balance line reactance which is beneficial for long-distance high-capacity power

transmission and distribution. This means that less power is needed at the power generation end to compensate for the voltage drops to deliver sufficient power.

CTS cable works as both a capacitor device and a transmission line in normal operating conditions, which provides the feasibility to offset the inductive reactance of wires by capacitive energy transfer between wires. Consequently, unlike any other existing cables, CTS can compensate for the reactive power used inductive loads.

Finally, CTS improves system performance. From a systematic view, CTS improves the load current and power quality, delivering more power to a local delivery point, so other lines connected to this point will benefit with a lesser power transfer requirement, resulting in less energy loss overall.

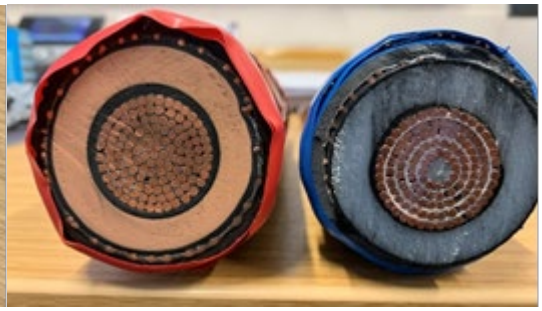

Fig 1: Cross section of CTS enamel (left) and CTS Multi-layer (right) Fig 2: Top view of CTS enamel (bottom) and CTS Multi-layer (top)

The research team developed two types of cable: CTS enamel and CTS multi-layer. Both achieve the improvements as described above, however they have slight differences depending on the voltage level applications.

The CTS cable reduces the need for AC booster transformers or HVDC converter stations which can comprise up to 40% of project capital investment, since CTS has materially less voltage drop than its traditional counterpart. CTS has also been designed so that it can be manufactured on existing production lines at cable manufacturers. Furthermore, the cables have been designed so that they can be joined together using existing equipment that power distribution networks have on their installation and maintenance vans. Both these features make the new cable cheaper to manufacture, install and maintain, increasing the likelihood of take up by the power distribution network.

In addition to the development of the cables, Dr Darwish's research team also developed a multilevel inverter that can generate electricity at high frequency and high power. This enabled the research team to be able to use small lengths of cable to emulate the conditions of long length cables that would be in use for power transmission. While multilevel inverters exist, there was no suitable inverter commercially available that could provide the appropriate level of power needed in the test and simulation environment. This inverter is now in use at Enertechnos.

3. References to the research (indicative maximum of six references)

Publications:

[1] Y. Yang, M. K. Darwish, M. S. Moghadam, C. Lucas-Clements, G. O'Brien, D. Quennell, "Power Cable Cost Benefit Analysis: A Critical Review," 2018, DOI: 10.1109/UPEC.2018.8541873, 53rd International Universities Power Engineering Conference (UPEC), 04 – 07

[2] Yang Yang, Mohamed K. Darwish, Mansour Salehi Moghadam, Dominic Quennell, Ashkan Daria Hajiloo, "Capacitive Transfer Cable and Its Performance in Comparison with Conventional Solid Insulated Cable", Electrical Insulation Conference, Calgary, Canada, June 2019.

Grant project:

The research project, *Capacitively coupled cables for transmission and distribution of electrical power*, was granted by Innovate UK from November 2017 to March 2019. It was awarded to Enertechnos, Brunel University and TWI. The total amount of grant was GBP1,094,152.

4. Details of the impact (indicative maximum 750 words)

In 2016-17 the UK lost 26,554 GWh in the transmission and distribution of electrical power which was an increase of 1.8% over the previous year [BEIS, Digest of UK Energy Statistics (DUKES) report 2018]. This loss is enough to power 7,000,000 homes and at retail prices, this power is worth GBP3,300,000,000 per annum. 1.5% of the UK's CO_2 emissions are attributable to power transmission losses. In comparison, the whole of the aviation sector equates to 2%. (OFGEM, Losses Incentive Mechanisms 2014). [E1]

Enertechnos was founded in 2013 to develop, patent and commercialise the Capacitive Transfer System (CTS) as a new concept in ultra-low loss cables based on capacitance technology. In 2017 the company, along with Brunel University and two other partners, secured InnovateUK funding of just over GBP1,000,000 to develop and test the cable to improve the capacitance of its initial prototypes. [E2, E3, E4]

The work of Dr Mohamed Darwish and his research team at Brunel University on this project [E5] was core to the development of this technology and advanced it to the point where Enertechnos has been able to secure future contracts and determine the future direction of Enertechnos as a company. The work undertaken to develop the CTS technology during this project led to the company winning the 2018-19 Rushlight Energy Environmental Award [E6].

Company Strategy

Enertechnos has been able to leverage GBP7,100,000 in funding to increase its staff. The company was started with 4 staff in 2013 and now has 9 full time staff. It had expected to grow to 14 staff by the end of 2020 but these have been delayed due to the Covid-19 Pandemic. [E7]

The company has also invested in its own in-house research and development capabilities. Recruiting two engineers trained by Dr Darwish to ensure ongoing knowledge transfer, Enertechnos has been able to work with its partners to model and develop solutions for its customers. Enertechnos stated: "The work of the research team has enabled the company to apply for further patents. We currently hold 15 granted international patents for this technology and have applied for three further patents since the project was completed in March 2019".

Market Development

Enertechnos' business strategy has been to licence the product to cable manufacturers rather than manufacture it themselves on existing production lines. A key approach to the research and development of the product was to ensure that cable manufacturers did not have to install new technology in order to encourage the adoption of their cables.

Meanwhile, the company has been using its expertise to work with power distribution companies and the wider power networks to create the opportunities for licenced cable manufacturers to sell the products in return for a 5% royalty from each sale.

Licences

Enertechnos has sold one licence to Tratos who were a partner in the InnovateUK project. The licence value is initially discounted at GBP250,000 per annum and covers manufacture of the product in Europe. It is expected that the cable manufacture for UK sales will be undertaken at Tratos's UK factory in Liverpool which will secure jobs in the north west. Enertechnos is in

discussion with other companies with a view to securing sales of a further four licences internationally by the end of 2020.

Sales to Distribution Networks

Enertechnos has been working closely with Western Power Distribution, a distribution network operator (DNO) that holds 4 of 14 UK licences. OFGEM requires all DNOs to reduce power losses and our solution is one that they have been keen to explore. Enertechnos has an agreement to deliver 15 miles of cable to be laid and tested. This had been planned for spring 2020 but has been delayed, partly due to Covid-19. It is now expected that this will be installed in Spring 2021. Following this trial, the company is planning to use the CTS cable underground in an area of outstanding national beauty in Wales where overhead cables are not permitted and the alternative option would be to install cable around the site. Enertechnos has a letter of intent.

Following these trials, Enertechnos is expecting Western Power to use CTS in its upgrade works across its four licensed areas. Its arrangement with Western Power is at this stage exclusive however, the company intends to extend its product to the other DNOs in the OFGEM network.

International Opportunities

Enertechnos' CEO was invited by American Electric Power to speak at an EPRI (Electric Power Research Industry) event to present CTS and its benefits in May 2019. This led to advanced discussions with an American cable manufacturer Southwire to have the first US Licence with some agreement for exclusivity. Similar to its work in the UK, Enertechnos is working with National Grid USA which holds a distribution licence in the states of Rhode Island, Massachusetts and New York. The company is seeking to use CTS as a solution to enable them to meet high power needs caused by increased demand due to products such as electric cars whilst managing the constraints created by the cables being laid in ducts. The increased capacity of CTS will enable the company to find a medium-term solution as it prepares for a long-term solution. If successful, Southwire will manufacture the CTS cable and supply the company. In addition, the company is in discussion with a number of national and international companies to utilise CTS for applications in sub-marine and mining environments.

Engagement with Policy

Enertechnos wants to raise awareness of power loss in cables and seeks to educate policy makers with a view to introducing CTS as a solution. To this end, the CEO has had numerous meetings with cabinet and shadow cabinet ministers including Kwasi Kwarteng MP – Minister of State for Business, Energy and Clean Growth and his shadow cabinet counterpart Dr Alan Whitehead MP; MPs from all the main UK political parties and officials at BEIS and OFGEM.

In 2019, the Enertechnos CEO was invited to participate on the OFGEM Working Group on RIIO-ED2 which will determine the price controls to regulate the electricity distribution networks from 2023 (report forthcoming – July 2020). This committee sets the criteria and incentives for energy loss reduction and its regulations will ultimately impact on the consumer. All these opportunities were made possible by Brunel's research and the availability of CTS as a solution to power losses.

As the CEO of Enertechnos states: "…we would not be in a position to be able to explore the variety of opportunities that we are had we not worked with Dr Darwish and his research team on the Innovate UK project. "

Carbon savings:

CTS provides a number of carbon savings. The reduction of energy loss by 10-20% along a CTS cable will enable a reduction in power generation at source. Overall, if we assume that 60% of

fuel comes from carbon sources, this could provide a carbon reduction of between 6 and 12%. [E5]

5. Sources to corroborate the impact (indicative maximum of 10 references)

All sources have been provided in PDF.

[E1] Enertechnos Policy Paper: The Road to 2050: Is our energy infrastructure ready to deliver net zero emissions: Enertechnos-Policy-Paper-The-road-to-2050-Is-our-energy-infrastructure-ready-to-deliver-net-zero-emissions.pdf

[E2] Article in Networks online - InnovateUK grant award: https://networks.online/gphsn/news/1000839/gbp1m-innovate-uk-grant-low-loss-cable

[E3] Article Newpower website: https://www.newpower.info/2018/01/innovate-uk-funding-aims-for-lower-loss-Ecables/

[E4] Brunel News reporting on InnovateUK grant: https://www.brunel.ac.uk/news-and-events/news/articles/1m-Innovate-UK-grant-for-revolutionary-low-loss-cable

[E5] Confidential report: the internal quarter meeting research reports (Q1 to Q6 meeting research reports)

[E6] Enertechnos Ltd - Winner of Rushlight Energy Environmental Award 2018-19: https://www.brunel.ac.uk/research/Centres/Power-Systems/Rushlight-Awards-Winner and https://www.rushlightevents.com/rushlight-awards/background/roll-of-honour/

[E7] Corroborating letter from Enertechnos