Institution: University of Manchester		
Unit of Assessment: 12 (Engineering)		
Title of case study: Increasing renewable energy and reducing customer bills: using managed connections and flexible demand response controls in the electricity network to support decarbonisation with the minimum infrastructure investment.		
Period when the underpinning research was undertaken: 2012 - 2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Haiyu Li	Reader	2012 – to date
Eduardo A Martinez-Ceseña	Research Fellow	2012 – to date
Jovica Milanovic	Professor	2013 – to date
Zhongdong Wang	Professor	2013 – June 2020
Luis F Ochoa	Professor	2012 – to date
Pierluigi Mancarella	Professor	2012 – to date
Christopher Jones	Research Fellow (2019 – present) Research Associate (2012 – 2019)	2012 – to date
Period when the claimed impact occurred: 2016 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

University of Manchester research, in collaboration with Electricity Northwest Ltd (ENWL), has developed and implemented a suite of control options across the electricity network of the North West of the UK. This avoided substantial cost-intensive upgrades, whilst enabling the integration of a growing number of renewable technologies into the network. ENWL are now able to provide "fast-reserve" services to the National Grid. Collectively, this research has:

- Fundamentally changed ENWL's policy making and investment process to assess network upgrade options;
- Provided evidence enabling ENWL to secure GBP18,000,000 funding for the UK's first actively optimised network;
- Since 2016, generated [text removed for publication] savings (to ENWL and customers) across the network;
- Since 2019, generated [text removed for publication] "fast-reserve" revenue for ENWL;
- Supported trials (Smart Streets) that could save up to 17 $MtCO_2e$ in the North West of England by 2060.

2. Underpinning research

Since 2012, research in the Department of Electrical and Electronic Engineering and the Tyndall Centre for Climate Change at The University of Manchester (UoM) has addressed three key areas relating to improved electricity network provision. Firstly, design of smart distribution networks and the subsequent decision-making processes that inform investment in the network [1]; secondly, new methods to actively manage the increasing levels of voltage and thermal (power flow) fluctuations across a network [2]-[5]; and thirdly, assessing the carbon impact of different network investment options [6].

Fluctuations in voltage and power flow detrimentally affect the overall stability of the network, impacting the security of electricity supply to both residential and commercial customers. These fluctuations result from the increasing number of renewable electricity technologies that are being connected to the network.

UoM research has explored the potential to use existing network assets (e.g., transformers and customers demand) to increase network capacity and flexibility. This sought to identify whether cheaper alternatives (compared to investing in new assets) could be used to manage voltage and power fluctuations. This involved a series of research projects funded through the UK Government's Ofgem Low Carbon Network (LCN) fund competitions (value to UoM, GBP1,554,716) that aimed to increase the capability and flexibility of the demand response in the ENWL network, balancing high power fluctuations between renewable generation and load demand of the electricity grid:

(i) **Capacity to Customers** project (C_2C; 2012 – 2015) explored smart distribution networks, and developed network investment planning models [1].
(ii) **Customer Load Active System Services** project (CLASS; 2013 – 2016) explored flexible and stagger controls of transformer tap changers at primary substations [2]-[5].
(iii) **Smart Street** project (2015-2019) explored flexible voltage optimisation between high-voltage (HV) and low-voltage (LV) networks, in order to improve the management of connections.

Specific key findings that resulted from these projects include:

- For the first time, the economic and social value of 'smart' demand-side response (DSR) solutions (managed connections) compared to traditional asset-heavy investments was quantified. The novel probabilistic tool developed by UoM - Real Options Cost Benefit Analysis (RO-CBA) - enabled modelling and comparison of multiple investment strategies. This demonstrated that DSR can reduce overall costs for both networks and end customers [1];
- Through the C_2C and CLASS projects, data were obtained to develop a novel time-varying voltage-demand model analysis tool; establish a voltage-load relationship matrix; and characterise different voltage load profiles [2]. Precise, real-time information is fundamental in actively managing voltage and demand fluctuations in the network;
- A method of flexible controls of primary substation tap changers to unlock time-varying load demand was proposed. By exploiting the positive correlation between supplied voltage and demand, flexible load management is possible, without needing to directly involve the customer [3];
- The level of load demand reduction flexibility that can be unlocked through voltage-led load management (a reduction in active power during normal operating conditions) to provide valuable balancing services was quantified [4]. Few previous studies explored the varying load management capabilities that result at different times (both daily and seasonally). The UoM methodology [4] was trialled in CLASS to quantify the aggregated demand reduction available at times when flexible load management services were required;
- The flexible control of primary substation transformer tap staggers was demonstrated as a method for unlocking reactive power absorption capabilities in power networks. Tap stagger techniques were more economically viable than other reactive power absorption methods, such as using inductive element/reactors, and can also reduce voltage damping and power overshoots during transient states [5];
- The carbon emissions savings that would result from different network asset investment strategies were quantified. The UoM carbon assessment methodology [6] combined for the first time, life cycle assessment (LCA) and network impact analysis, and was applied in Smart Streets to quantify the potential carbon benefits that different scenarios would provide.

3. References to the research

The research is published in top journals in the field [2,4,5,6]. Output [5] was awarded the prestigious IEEE Power Energy Society (PES) Prize Paper 2017. All citation counts are from Web of Science (October 2020).

[1] J. A. Schachter, **P. Mancarella**, J. Moriarty, R. Shaw, (2016) Flexible investment under uncertainty in smart distribution networks with demand side response: Assessment framework and practical implementation, *Energy Policy*, **97**, p439 –449, DOI: 10.1016/j.enpol.2016.07.038 (15 citations)

[2] X. Tang, K. N. Hasan, J. **V. Milanović**, K. Bailey and S. J. Stott, (2018) Estimation and validation of characteristic load profile through smart grid trials in a medium voltage distribution network , *IEEE Transactions on Power Systems*, **33** (2), p1848-1859, DOI:10.1109/TPWRS.2017.2740563 (10 citations)

[3] A. Ballanti, **L.F. Ochoa**, K. Bailey, S. Cox, (2017) Unlocking new sources of flexibility: CLASS: The world's largest voltage-led load-management project, *IEEE Power and Energy Magazine*, **15** (3), p 52-63, DOI: 10.1109/MPE.2017.2660799,(7 citations)

[4] A. Ballanti**, L.F. Ochoa**, (2018) Voltage-led load management in whole distribution networks", *IEEE Transactions on Power Systems*, **33** (2) pp 1544-1554, DOI:10.1109/TPWRS.2017.2716945, (11 citations),

[5] L. Chen, **H. Li**, S. Cox, and K. Bailey, (2016) "Ancillary Service for Transmission Systems by Tap Stagger Operation in Distribution Networks. *IEEE Transactions on Power Delivery*, **31** (4), p1701-1709, DOI:10.1109/TPWRD.2015.2504599 (12 citations),

[6] **Jones, C**, **Gilbert, P**, Raugei, M, **Mander, S** & Leccisi, E (2017) An Approach to Prospective Consequential Life Cycle Assessment and Net Energy Analysis of Distributed Electricity Generation, *Energy Policy*,**100**, DOI:10.1016/j.enpol.2016.08.030 (24 citations)

4. Details of the impact

Context

ENWL supply electricity to over 5,000,000 customers in the North West of England, and are the largest electrical distribution network operator (DNO) in the UK. To help meet the UK government's 2050 net zero carbon emissions target, an increasing number of low-carbon and renewable technologies are being connected to the network. However, renewable energies can cause fluctuations in voltage and power flow, which affect the overall stability and security of the network. The regulator Ofgem will also require DNOs to take a more active role in carbon reduction in the next price control period (RIIO-ED2) beginning in 2023. ENWL identified that they needed to significantly invest in and enhance their network capacity (e.g., bigger lines, substations, and other infrastructures) in order to manage the voltage and thermal fluctuations that result from these additional connections. However, new investments are costly and have a significant carbon and material consumption penalty. Actively managing these voltage and power fluctuations can avoid specific costly infrastructure investments whilst improving and enhancing existing infrastructure assets. UoM collaborated with ENWL to support a strategic approach to enhancing network performance and minimising investment needs.

Pathways to impact

In 2012, ENWL commissioned UoM to undertake a series of research projects to inform more effective network investment. The C_2C project assessed the capability of ENWL's distribution networks to cope with both an increasing number of customers as well as integrating renewable power generation. Building on the subsequent project reports, ENWL identified the need to explore new ideas to further increase network capacity, which led to the CLASS (2014-2016) and Smart Street (2015-2019) projects.

As part of these projects, UoM developed a range of models and planning tools that facilitated ENWL to implement flexible demand-side response controls to increasing network capacity. Trials run by ENWL identified the success of these projects to provide improved network capacity and flexibility, whilst substantially reducing the financial investment (and embedded carbon) in new assets.

Reach and significance of the impact

Improved network capacity through connection management

Spare capacity in the distribution network is vital to ensure a reliable electricity supply to customers. As we transition to a net-zero economy, the demands placed upon local electricity networks are changing (e.g., solar photovoltaics feeding in, increased demand due to electric vehicles and heating): in some areas any previous spare capacity will no longer be sufficient to ensure reliability of supply. Given investments to add capacity are costly, UoM research developed a planning tool – RO-CBA – to demonstrate where investment savings can be made across a network [1].

Using RO-CBA, this research [1] identified that 'managed connections' reduce the need for new infrastructure by effectively obtaining spare capacity from customers who reduce their consumption when contingencies occur (such as the failure of a line). In 2016, as a result of the UoM research [1], ENWL fundamentally changed their policy making and investment process, and rolled out managed connections across their entire network. This approach, and the RO-CBA tool, are now integrated into their business-as-usual assessment of network upgrade options. [Text removed for publication]. This tool [1] has led to improved management of network connections for an increasing number of customers whilst maximising the integration of renewable power generation [1]: through maximising spare capacity in the existing network, the network is better able to cope with increased demands from renewable technology. Overall this has increased the confidence in which ENWL can safely connect a greater level of (intermittent) renewables to the network. [Text removed for publication].

Flexible demand response management techniques improve network stability

i) CLASS

Responding to the power and voltage fluctuations described above, ENWL applied the learnings from the CLASS and Smart Streets projects to improve network stability. Following CLASS, ENWL installed new monitoring equipment and 'voltage controllers' on over 60 primary substations at tactical points on the distribution network, as recommended through the UoM research [2-5]. Evaluation by ENWL has confirmed this can save its customers around GBP100,000,000 over the next 25 years [B]. The CLASS method can be implemented at a primary substation 57 times faster and 12 times more cheaply than traditional network reinforcement [C].

The CLASS research [2-5], successfully applied in the North-West, has also been approved for national use. The National Grid Electricity System Operator (NGESO) is responsible for managing the electricity system across the UK. NGESO has confirmed that the ENWL CLASS passed testing for the low frequency static response service in 2018, and the fast reserve service in 2019 [D]. This allows CLASS to participate in the Firm Frequency Response (FFR) and Fast Reserve (FR) tendered markets – essentially enabling the National Grid to 'buy' load from DNOs. CLASS provides a more cost-effective service than previously available: according to NGESO [E][F], the accepted ENWL2 method (i.e. ENWL CLASS), offers the lowest firm energy fee (GBP80 per MWh) in the tendered market. [Text removed for publication].

Since March 2019, the CLASS method has been successfully activated [G] [Text removed for publication].

The CLASS programme has allowed DNO/DSOs to optimise the effectiveness of their infrastructure investment by taking a strategic approach to the assessment of managed connections and flexible demand response. These approaches have made significant savings for both the network operators and consumers and allow the decarbonisation of electricity networks to be delivered more rapidly and with lower levels of investment and disruption.

ii) Smart Streets

Smart Streets was the first UK demonstration of a fully centralised low voltage network management and automation system [H]. Smart Streets stabilises voltage by using new controllable switching devices integrated into the ENWL network management system. Subsequently, the supply voltage to customers is reduced to an optimum level – known as conservation voltage reduction – enabling both the network and customer appliances to work more efficiently [I].

Smart Streets uses assets deployed as part of the CLASS and C_2C projects, and additional HV and LV network models developed by UoM, to analyse the impact and benefits of the Smart Streets trials, as well as undertaking a carbon impact assessment (based on the methodologies in [6]) [G]. ENWL used these findings to support their application for GBP18,000,000 as part of the Innovation Rollout Mechanism (IRM) from Ofgem and the UK Government Department for Business, Energy and Industrial Strategy (BEIS), to roll out voltage optimisation across the LV networks. [Text removed for publication].

The Smart Streets method enables customer appliances to operate more efficiently which can extend the life of the equipment as well as the more immediate benefit in reduced operating cost [J]. Further, the carbon impact assessment demonstrated Smart Street could provide carbon savings of up to 17 $MtCO_2e$ in the North West by 2060 [K]. By controlling voltage on ENWL's LV network, Smart Streets can reduce customer electricity bills by up to GBP60 to GBP70 a year, reduce carbon emissions and provide more flexible solutions to connect low-carbon technologies into the network, all without reducing power quality [G][H]. Given the direct financial benefit to customers, ENWL have prioritised the selection of substations that overlap with customers identified as living in fuel poverty. Once fully integrated into ENWL's network management system, this will create the UK's first actively optimised network [H].

5. Sources to corroborate the impact

- [A] Letter of support for RO-CBA from Flexibility Solutions Manager, Electricity North West, June 2020
- [B] ENWL Press Release (November 2017) - *Energy saving pioneering CLASS project rolls out across North West* [PDF, and available at https://bit.ly/2XYercw]
- [C] Ofgem (2015) *Customer Load Active System Services (CLASS) Close Down Report*, Ofgem Tier 2 LCN, September 2015, [Available at https://bit.ly/3p6cWVA]
- [D] Letter of support from Power Responsive Manager, National Grid ESO, June 2020
- [E] NGESO's Fast Reserve Post Tender Assessment WebEx (Presentation) June 2019
- [F] Letter of support from Future Networks Manager, Scottish Power, June 2020
- [G] Letter of support for CLASS/Smart Streets projects from Head of Network Innovation, Electricity North West, June 2020
- [H] Smart Street Project webpages [Available at https://bit.ly/3p6mRui and https://bit.ly/3iDaFyI]
- [I] Smart Street Summary Factsheet, ENWL
- [J] Smart Street Close Down Report, April 2018, ENWL
- [K] Smart Street Carbon Accounting Report, January 2018, ENWL and UoM