Institution: University of Manchester

Unit of Assessment: UOA 12 (Engineering)

Title of case study: Improved designs of high voltage overhead lines enable increased transmission capacity, providing environmental and financial benefits

Period when the underpinning research was undertaken: 2004 – 2016

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:
Simon Rowland	Professor	2003 – present
Ian Cotton	Professor	1998 – present
Iain Dupere	Reader	2006 – 2020
Konstantinos Kopsidas	Senior Lecturer (2010 – 2020) Research Associate (2009 – 2010)	2009 – 2020
Vidyadhar Peesapati	Knowledge Transfer Fellow and Research Fellow	2010 – 2020
Roger Shuttleworth	Senior Lecturer	2003 – present
Jeff Robertson	PDRA	2004 – 2008
Antonios Tzimas	PDRA	2008 – 2013

Period when the claimed impact occurred: August 2013 – December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Increasing renewable energy is necessary to meet UK and global carbon emission reduction targets. To connect renewable energy technologies into the energy network, the power capacity of existing electricity infrastructure must increase. University of Manchester research has developed models and methods that have: improved the selection of conductors; developed composite insulators; and improved understanding of the electrical and mechanical performance of conductors. Collectively, this has enabled new overhead line designs to be produced that increase power flow whilst reducing existing noise problems. Specifically:

- National Grid estimate knowledge generated has provided cost savings of approximately GBP11,000,000 to the UK energy network, and benefits valued in the millions of GBPs for North American energy transmission system operators;
- Design and testing support underpinned a new design (T-pylon) for a GBP214,000,000 overhead line to connect Hinkley Point Nuclear Power Station to the National Grid. The reduced visual impact is valued between GBP12,000,000 and GBP39,000,000;
- The research has helped solve long-term noise issues on a Cheshire (UK) electricity line, providing immediate noise relief to the community;
- National Grid have secured GBP8,100,000 to further research the uprating of overhead lines.

2. Underpinning research

The High Voltage Laboratory at the University of Manchester (UoM) undertakes research into transmission, distribution, expansion and innovation of the UK energy supply network. This is driven by the need for innovation in high voltage transmission overhead line infrastructure, especially in order to meet national scale carbon targets. Funded by industry, the UK Government and the EU, there are three distinct, globally leading areas of research:

i) Polymeric insulators and composite cross-arms

Between 2004 and 2013, four research projects (total value GBP890,000) on ageing of polymeric insulators were funded by National Grid (two projects), Scottish and Southern Energy (SSE) and UK Power Networks. These projects resulted in seminal work on ageing processes, especially on silicone rubber materials [1], and frameworks for management of such assets in service [2]. National Grid and SSE funded further projects (GBP473,000) on composite cross-arms (2010-2014). This latter work, on novel insulating overhead line structures, identified opportunities for tower compaction by integrating the tower cross-arm and insulator functions, and resolving the challenges associated with electric field grading of complex insulator structures [3]. This research challenged the existing qualification procedures for insulators being used for structural purposes – proving the capability of the novel, non-circular insulator cross-section. This procedure is now patented (patent WO2011/021006 A2 granted in UK, India, Canada, China, and Brazil), and detailed monitoring of this insulation has improved confidence in both technology and application.

ii) Conductor electromechanical performance

Starting in 2007 within the 4-year EPSRC/Supergen-Amperes project, a performance model of overhead line (OHL) conductors was developed that provided improved design rules [4]. Following this, a knowledge transfer project funded by National Grid (2011-2012) further developed the methodology for calculating conductor electromechanical performance and ageing under operating conditions [5]. This then led to a UK Power Networks (UKPN) project (2012-13), which considered case studies for increasing UKPN's OHL corridor power efficiencies and generated knowledge of the implications of different novel conductor technologies (in particular sag, tension and reliability constraints). Building on [4] and [5], research funded by The Centre for Energy Advancement through Technological Innovation (CEATI, 2017-18) on conductor vibrations identified that standard practices are not suitable for novel HTLS conductor technologies.

iii) Conductor acoustic performance

National Grid funded the GBP781,000 'Acoustic Emissions From Overhead Lines' project (October 2009 to February 2014). A unique experimental facility was developed to directly measure noise from energised conductors. This work produced an evaluation strategy for noise generation from various conductors [6], which National Grid used to select optimal conductor designs. As part of the research, field-modelling techniques over a range of size scales were developed and an understanding of noise generation dynamics was generated from smaller scale measurements and modelling. For the first time, the root cause of low-frequency noise from a particular type of conductor, found to behave anomalously by National Grid, was established - the acoustic emission below 1 kHz is determined by the size distribution of surface water droplets.

3. References to the research

This research was funded by industry (National Grid, SSE, UKPN), and EPSRC. The following references to research output are all peer-reviewed papers. Citation counts are from Web of Science (November 2020).

[1] **S. M. Rowland, J. Robertson**, Y. Xiong, and R. J. Day, (2010), "Electrical and Material Characterization of Field-Aged 400 kV Silicone Rubber Composite Insulators", *IEEE Transactions on Dielectrics and Electrical Insulation*, 17 (2), pp. 375-383, DOI:10.1109/TDEI.2010.5448091 (45 citations)

[2] **A. Tzimas**, E Da Silva, .**S M. Rowland**, B. Boumecid , M. Queen, and M. Michel (2012), "Asset Management Frameworks for Outdoor Composite Insulators", *IEEE Transactions on Dielectrics and Electrical Insulation*, 19 (6), pp. 2044-2054, DOI:10.1109/TDEI.2012.6396964 (6 citations)

[3] **S. M. Rowland**, R. Maclaren, **I. Cotton**, D. Chambers, **V. Peesapati**, C. Zachariades (2014), *Development of insulating cross-arms for compact HV lattice tower structures CIGRE Session 2014 B2-107*, CIGRE, Paris

[4] **K. Kopsidas** and **S. M. Rowland**, (2009), "A Performance Analysis of Re-conductoring An Overhead Line Structure", *IEEE Transactions on Power Delivery*, Vol. 24, pp. 2248-2256, DOI: 10.1109/TPWRD.2009.2021042 (28 citations)

[5] **K. Kopsidas**, B. Boumecid, and I. P. Cooper, (2016), "Overhead line design considerations for conductor creep mitigation", *IET Generation, Transmission & Distribution*,10 (10), pp. 2424-2432, DOI: 10.1049/iet-gtd.2015.1186 (5 citations)

[6] Qi Li, **S M Rowland, I. Dupere**, and **R. Shuttleworth**, (2017), "Acoustic noise evaluation for overhead line conductors using an anechoic chamber", *IEEE Transactions on Power Delivery,* 32 (4), pp.1835-1843, DOI:10.1109/TPWRD.2016.2558153. (10 citations)

4. Details of the impact

Context of impact

The energy sector accounts for GBP86,600,000,000 of UK economic activity with National Grid's Electricity Transmission (NGET) group alone being responsible for over 7,200 km of overhead lines, and turning over GBP3,400,000,000 in 2018/19 [A]. Utility networks are historically robust, using traditional technologies to deliver power. As renewable energy is added into the network, capacity must be increased at specific locations. This, combined with growing consumer demand (through an increasingly electrified lifestyle, such as electric vehicles) and an ageing network that requires asset management, means these networks must now adapt to be able to continue to provide reliable electricity.

Pathway to impact

Since 2004, UoM have been a strategic partner of NGET and this research has directly fed into industry led projects [A]. The three distinct research themes combine to benefit the design of overhead lines. The research has optimised holistic overhead line design and utilisation, which is an improvement on the previous approach of optimising individual components.

Between 2004 and 2014, NGET funded research [1-3] into ageing of composite insulators in overhead lines. Subsequently, in 2013, Rowland, Cotton and Peesapati were invited to join the team responsible for supporting the design, finite element analysis modelling and type-approval of the new NGET line designs [A]. They therefore directly fed the research into practice. In November 2020, using the lessons from the UoM research, NGET secured GBP8,100,000 of funding from Ofgem's Network Innovation Competition (NIC) to research the uprating of their overhead lines [B], with an additional GBP1,100,000 being funded by National Grid [C].

Similarly, the EPSRC Supergen Amperes project (2007-2010 [4]) and subsequently the EPSRC Supergen Top and Tail Project (2011-2014) brought UoM together with multiple utility companies. Following the end of the Amperes project, Kopsidas continued to work with NGET and UKPN through a Knowledge Transfer Account project on real network constraint issues [5]. This knowledge has also been transferred into practice internationally through FP7 activity and work funded by the Canadian consultancy, CEATI [D].

In 2014, NGET successfully trialled the acoustic modelling solutions [5] on a problem line in Cheshire, proving the viability of the UoM research [6]. Ofgem Network Innovation Allowance (NIA) funding (GBP875,000) was obtained to replace the existing (noisy) conductor and prove the technical modelling [A].

Reach and significance

i) Environmental benefits from novel designs

UoM work on composite insulator reliability [1,2] and its application [3] enabled NGET to accept wide-bodied silicone insulators onto its lines as a standard product. Type-approval regimes and design capabilities developed by UoM enabled the novel T-Pylon design, shown in Figure 1 [A]. [Text removed for publication]. The new design has reduced the environmental impact of the line, and will enable the connection of the new GBP20,000,000,000 Hinkley Point C Power Station, with reduced impact on the community and environment. This connection is a key part of the government's plan to reduce carbon emissions and will help deliver power to six million homes [E]. An NGET commissioned 'willingness-to-pay study' shows the benefit provided by the T-pylons is valued at between GBP12,000,000 and GBP39,000,000 [F]. [Text removed for publication].

Figure 1. First T-Pylons erected as a trial in 2015 by Balfour Beatty at Eakring

The UoM work on composite cross arms [3] directly led to NGET's programme of tower upgrading, using retro-insulated cross-arms. NGET have committed to a GBP9,000,000 research programme (commencing early 2021) to develop an innovative method for uprating overhead lines, allowing the voltage on 275 kV overhead lines to be increased to 400 kV [C]. NGET predict "*uprating lines in this way could allow 45% more power to be carried on some existing routes and support significant reductions in UK CO_2 emissions – 39,000 tonnes. This could deliver up to GBP286,000,000 of efficiencies to consumers*…" [C].

NGET have used the framework developed in [6] [Text removed for publication]…and resulted in the Award for the Built Environment Category in the 2015 IET innovation awards [G].

ii) Improved operating procedures

In 2019, Balfour Beatty was awarded the GBP214,000,000 contract to deliver the new T-pylon overhead line at Hinkley Point [H]. [Text removed for publication].

iii) Informing investment decisions

Low-noise conductor designs can be up to five times more expensive than standard conductor designs. However, the UoM research [6] demonstrated that the selection of these conductors significantly reduces the risk of adverse audible noise impacts in noise sensitive locations. [Text removed for publication].

3M also acknowledge the value of the UoM research measurements. Following the trials conducted as part of the NGET funded research [6], NGET selected the 3M ACCR

(Aluminium Conductor Composite Reinforced) composite overhead conductor because it was quieter than comparable conductors. [Text removed for publication].

iv) Contributing to professional development and expertise in the UK National Grid
Since 2017, NGET have used UoM research [1-6], and the expertise of Cotton and Kopsidas [text removed for publication]. Cotton is part of the Technical Advisory Board for the project [A].

To date, NGET have recruited 8 UoM PhD graduates from the high voltage laboratory team following the research projects described above. Since 2014, UoM have also trained 31 existing NGET employees through the Electrical Power Systems Engineering MSc. [Text removed for publication].

5. Sources to corroborate the impact

[A] Letter of support from Head of Innovation, National Grid, April 2020
[B] Letter of support from Head of ET Innovation and Engineering Services, National Grid, January 2021
[C] Press Release: "£9.2m Electricity research project to save 39,000 tonnes of CO_2 gets go-ahead" November 2020, Available at: https://www.nationalgrid.com/30-november-ps92m-electricity-research-project-save-39000-tonnes-c02-gets-go-ahead
[D] Letter of support from Director Transmission and Distribution, CEATI, June 2020
[E] Hinkley Point C – contracts and project documents. Available at: https://www.gov.uk/government/collections/hinkley-point-c
[F] Hinkley-Seabank – Consultation on Final Needs Case and potential delivery models, OFGEM, 30 August 2017 (Section 2.25)
[G] Press release: The 2015 IET innovation awards, Built Environment Category (Archived website – pdf on file)
[H] Press release: T-pylon contract value, January 2019, available at: https://www.balfourbeatty.com/news/balfour-beatty-awarded-214-million-hinkley-point-c-overhead-line-contract-for-national-grid/
[I] Letter of support from Strategic Key Account Manager, 3M, May 2020
[J] National Grid invests in quieter conductors, June 2016, available at: https://www.3m.co.uk/3M/en_GB/energy-uk/stories/full-story/?storyid=f9aa133e-bc07-4fde-bd3c-6067bb37542e