Institution: University of Southampton

Unit of Assessment: 13 Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: 13-07 Reliable Cable Systems for Energy Security

1. Summary of the impact

The supply of electrical energy to centres of demand is an increasingly important issue as our power generation sources decarbonise. Without innovation in our use of high voltage cables, security of supply to our major cities cannot be guaranteed. Our research has:

- Identified how outdated international standards governing the rating of power cables can undermine network performance.
- Developed improved rating methods which will save National Grid £1.2 million annually.
- Informed new international technical guides.
- Designed, in conjunction with major industrial partners, cables that optimise transmission for lower operational costs, minimise the risk of network failure and cut carbon emissions.

2. Underpinning research

The transmission of electricity through cables is an increasing issue as the power demand of large urban areas rises, as we seek to minimise the impact of overhead lines on the environment and as offshore renewable generation grows. To meet this challenge, it is imperative that we must maximise the ability of our electrical networks to transmit power reliably from generators to load centres. This need was emphasised in, for example, the UK government's 2003 *Energy White Paper* and the 2012 UK's *Energy Security Strategy* document. Our research responds to this by addressing two key questions relating to cable systems:

1. How much power can reliably be conveyed through any given cable link and for how long?
2. How can cables be redesigned to increase their transmission capability?

This impact case study addresses both of these questions in a concerted way.

Underpinning work at Southampton has informed international standards for rating cables since the 1970's, many of which are still in use today. However, increasing awareness of the limitation of these approaches led UK network operators to fund a range of projects at Southampton to enhance their understanding of key issues and hence increase network capabilities [G1-G3]. Key advances have involved the development of advanced finite element models, supported by bespoke experimental facilities for validation. Work led by Prof Paul Lewin in 2005, developed numerical models for buried cable systems that coupled the physics of heat flow and moisture transport. Advances in computing hardware have facilitated the creation of bespoke 2D finite element models of buried cable systems [3.1] eventually leading to the creation by Dr James Pilgrim (initially PhD student, now Lecturer) of full 3D models of cooled joint bays from critical London cable circuits in 2008 [3.2]. Driven by the trend for the greater use of cable tunnels in London, new methods were created for rating ventilated tunnels [3.3] and cables mounted in surface level concrete troughs [3.4] using combined thermal analysis and fluid dynamics (2008-2012).

An alternative approach to the problem of cable ratings is to re-design the cable to allow enhanced power transmission. Research into the electrical and mechanical behaviour of bespoke polyethylene blends began in the mid-1990s and demonstrated that material systems could be designed with significantly enhanced characteristics through carefully controlling the molecular composition of the system, such that the required microstructures self-assembled. The extension of this concept to high temperature insulation systems based on polypropylene was led by Prof Alun Vaughan, beginning in 2006 within the Engineering and Physical Sciences Research Council (EPSRC) Amperes Supergen programme [G3] and demonstrated its viability within the laboratory [3.5]. However, the use of isothermal processing conditions rendered direct technology transfer to industry impractical. Further follow-on funding from the Technology Strategy Board, EPSRC and a consortium of industrial partners in 2008 [G4] then developed a technologically practical non-isothermal manufacturing process [3.6]. Together with large scale system studies and cable rating analysis, the work demonstrated the value to system operators of cable systems capable of operating at higher temperatures, with current ratings increased by up to 28%. On-going work is extending this concept to high voltage DC cables, with further support from ABB (Switzerland) [G5] and EPSRC [G6].

3. References to the research (best 3 publications starred)

Publications (Industrial collaborators identified in bold)

[3.1] Swaffield, D. J., Lewin, P. L. and **Sutton, S. J.** Methods for rating directly buried high voltage cable circuits, 2008, *IET Generation, Transmission & Distribution*, 2 (3). pp. 393-401. ISSN 1751-8687

[3.2] Pilgrim, J. A., Swaffield, D. J., Lewin, P. L., **Larsen, S. T. and Payne, D.** Assessment of the impact of joint bays on the ampacity of high voltage cable circuits, 2009, *IEEE Transactions on Power Delivery*, 24 (3). pp. 1029-1036. ISSN 0885-8977

*****[3.3] Pilgrim, J., Swaffield, D., Lewin, P., **Larsen, S. T., Payne, D. and Waite, F.,** Rating Independent Cable Circuits in Forced Ventilated Cable Tunnels, 2010, *IEEE Transactions on Power Delivery,* 25 (4). pp. 2046-2053. ISSN 0885-8977

[3.4] Pilgrim, J. A., Lewin, P. L., Larsen, S. T., Waite, F. and **Payne, D.,** Rating of cables in unfilled surface troughs, 2012, *IEEE Transactions on Power Delivery* , 27, (2), 993-1001

*****[3.5] Hosier, I. L., Vaughan, A. S. and Swingler, S. G., An investigation of the potential of polypropylene and its blends for use in recyclable high voltage cable insulation systems, 2011, *J. Mater. Sci.* 2011, 46. pp. 4058-4070 (DOI: 10.1007/s10853-011-5335-9).

*****[3.6] Green, C. D., Vaughan, A.S., **Stevens, G. C.**, **Sutton, S. J.**, **Geussens, T.** and **Fairhurst, M. J.**, Recyclable power cable comprising a blend of slow-crystallized polyethylenes, 2013, *IEEE Transactions on Dielectrics and Electrical Insulation*, 20, (1), 1-9 (DOI: 10.1109/TDEI.2013.6451335).

Key Grants (Southampton investigators identified in bold)

[G1] **Prof P L Lewin**, Environmental Cable Rating Parameters, National Grid Company, 1994 – 1997, £134,740.

[G2] **Prof P L Lewin**, Ratings of Cables in Tunnels (RoCiT), National Grid plc, 2007 – 2012, £163,677.

[G3] **Prof S G Swingler**, Enhanced Management and Performance for a Sustainable UK Energy Infrastructure, EPSRC Grant EP/D034531/1, 2006 – 2010. Total value £2,484,941.

[G4] **Prof A S Vaughan & Prof P L Lewin**, Sustainable power cable materials technologies with improved whole life performance, EPSRC/TSB Grant TS/G000239/1, 2008 – 2010. Total value, £659,213 – £192,156 from EPSRC.

[G5] **Prof A S Vaughan**, Polymeric Materials Development for HVDC Cable Applications, ABB, 2011-2013. Total value £305,000 **CONFIDENTIAL.**

[G6] Prof T Green et al (including **Prof P L Lewin, Prof S G Swingler & Prof A S Vaughan** from Southampton), Energy Networks Grand Challenge: Transformation of the Top and Tail of Energy Networks, EPSRC Grant EP/I013636/1, 2011 – 2015, Total value £4,723,735.

4. Details of the impact

Linking Research to Impact

The impact delivered in this case study has been generated through the following mechanisms:

(i) A sustained programme of **engagement with key beneficiaries** has led to **relationship development**. Evidence of the success of this is provided by our long-standing Framework

Agreement with National Grid (NG); we are one of just four UK universities to benefit from a strategic alliance with this major engineering organisation. The value of this is based upon a process whereby dialogue helps to address NG's existing issues, while also informing us of future challenges. The cable ratings element of this impact case study shows how sustained engagement with system operators (NG and EDF Energy Networks – now UK Power Networks) highlighted shortcomings with established procedures and, subsequently, led to novel solutions.

(ii) The dielectrics element of this impact case study provides evidence of our **agile approach to opportunity**. This began as a PhD project with NG, which subsequently developed through EPSRC and TSB projects. The latter involved NG and also benefitted from Dr Simon Sutton [5.1] moving from NG to Dow Chemicals, which enabled us, then, to access this multinational polymer supplier. Subsequently, by exploiting other **relationships developed** with leading cable manufacturers (e.g. ABB and General Cables [5.2]) we have generated **follow-through** in terms of acceptance of our technology.

Much of the above research has been reliant upon the Ofgem's Innovation Funding Initiative, a requirement of which is that it can "enhance the technical development of distribution networks and can embrace asset management from design through to construction, commissioning, operation, maintenance and decommissioning" [5.3].

Impacts during the REF Period

1. Economic Impact on Business

The application of finite element tools to cable ratings problems, coupled with experimental validation, has led to improved techniques that greatly enhanced accuracy, thereby improving the performance of electricity network businesses through the minimisation of both risk and constraint costs, while maximising asset utilisation. NG has made savings of £1.2m per annum as a result of employing improved cable ratings methodologies [5.4]. Potential future losses have been mitigated by improved methods of risk assessment for critical plant. Translating our knowledge across to the offshore wind sector has informed future design choices on wind farm export cables at Centrica Renewable Energy Ltd [5.5]. Shifts in expenditure profiles within corporate budgets are evinced by the substantial and sustained industrial funding into novel dielectric systems won within the REF period: SUSCABLE project (NG, Dow Chemicals), £467k (total value including EPSRC/TSB contribution £659k) (2008-2010); Polymeric Materials Development for high voltage direct current Cable Applications projects (ABB Switzerland), total value £305k (2011-2013); SUSCABLE II project (Nexans, Silec, Scottish Power, ORE-Catapult): total value £480k (2013-2016) [5.1, 5.2].

2. Environmental Impact

Improved modelling of ventilated tunnels is having a traceable impact on particular projects in terms of reduced environmental impact – reductions in cooling system running using our new control scheme has been estimated to deliver electricity cost savings of around 60% [5.4]. Our development of high performance thermoplastic cable dielectrics is affecting international cable manufacturers and polymer suppliers; the technologies we have developed are less energy intensive in production, are fully recyclable at end of life and have been shown to offer network businesses enhanced operational flexibility by allowing greater power transfer capabilities than existing products [5.6].

3. Knowledge Transfer & Increased Business Capability

Documented changes in the knowledge and capability of NG have occurred as evinced by their adoption of methods we developed. Specifically, NG now have enhanced thermal modelling capability within the business, with the methods developed under [G2] now part of their standard circuit rating tool. We have also partnered with members of the NG supply chain, for example Balfour Beatty Utility Solutions Limited (BBUSL) requested a build of the cable tunnel modelling software for their engineers. This broadens the impact beyond the UK, with BBUSL using the tools in their design work for other countries [5.7]. We have also been invited to attend design meetings to provide additional design verification services where our new methods can provide solutions for problems which the present international standards cannot. Our novel dielectric materials have been patented in conjunction with our industry partners - WO 2012/044523A1 and US provisional patent application 61/617,347 (subsequently granted as WO/2013/148028).

4. Change in Business Practice

We have developed a track record for implementation of our research work within companies such as National Grid. The methods developed in [3.2] for modelling water cooled cable circuits and [3.3] for cable tunnels have been used to evaluate required levels of refurbishment on cable circuits in London, allowing the necessity of capital expenditure to be challenged in a more robust way than previously possible. Our tools permitted Balfour Beatty Utility Solutions Limited (BBUSL) to engage in a more detailed thermal analysis of cable circuits under refurbishment than had ever been achieved before, influencing the design processes used and reducing system risk [5.7].

5. Impact on Practitioners

Industrial acceptance of radical technological change can be difficult to achieve, especially where reliability and long deployment times breed conservative approaches. Effective communication is then essential so, in parallel with our research, we continue to engage with a broad range of potential stakeholders, outside our research funders. Examples of this include our involvement with the International Council on Large Electronic Systems (CIGRE) working groups (e.g. B1.35 and D1.40), the production of industry-facing documents ranging from the "*Nanocomposites and other Advanced Materials for Cable Networks*" review for EA Technology's Strategic Technology Programme [5.8]. The forthcoming CIGRE B1.35 guide on current rating calculations [5.9] draws on our research and references our research, as does the forthcoming CIGRE D1.40 brochure on functional materials [5.10].

6. Impact on Society

We have sought to engage the public with our work on maximising the capability of cable networks through the Café Scientifique programme [5.11]. By focusing on a potentially disruptive future technology (Electric Vehicles), and using our work to demonstrate the impact of shifts in consumer behaviour on our energy networks, we have sparked debate among our audiences as to the most suitable policy responses, along with the true cost implications of such changes. Further prominence among the wider technical public was gained through our viewpoint article in The Engineer [5.12].

5. Sources to corroborate the impact

[5.1] Contact for verification at EPRI International, Inc.

[5.2] Contact for verification at ABB, Baden, Switzerland

[5.3] Ofgem Innovation Funding Incentive (http://www.ofgem.gov.uk/Networks/Techn/NetwrkSupp/Innovat/ifi/Documents1/Web%20Text%20Innovation%20Funding.pdf)

[5.4] Contact for verification at National Grid, Warwick

[5.5] Contact for verification at Centrica Renewable Energy Ltd: CONFIDENTIAL PROJECT

[5.6] http://www.omnexus.com/news/news.aspx?id=22800

[5.7] Contact for verification at Electricity Alliance East (BBUSL)

[5.8] http://www.eatechnology.com/strategic-technology-programme

[5.9] http://b1.cigre.org/Members-Area/WG-B1.35-Guide-for-rating-calculations

[5.10] http://d1.cigre.org/Members-Area/WG-D1.40-Functional-Nanomaterials-for-the-Electrical-Power-Industry

[5.11] http://virtualcafe.ecs.soton.ac.uk/car/main

[5.12] http://www.centaur2.co.uk/emags/theengineer/te-160712/ Working Up Energy, p28