Institution: The University of Bath

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

Title of case study: Using Network Charges to Maximise the Efficiency of Electricity Distribution Networks

1. Summary of the Impact

Research at Bath has developed a new network charging methodology, known as "*Long Run Incremental Cost (LRIC) pricing for electricity distribution systems*". The methodology enables the calculation of location-specific annual network charges for electricity generators and suppliers. It has replaced the flat-rate charging approach used by the industry for the previous 25 years. Bath's work on LRIC has led to: 1) **major impact on government policy**, because in 2008 the UK regulator Ofgem required Distribution Network Operators (DNOs) to adopt LRIC as an industry standard, using the evidence provided by Bath that LRIC's uptake can lead to efficiency savings over the next 20 years of about £200 million for DNOs, and 2) **major impact on industrial practice**, because the subsequent industrial adoption of LRIC over 80% of the UK distribution area has enabled the DNOs to promote efficient use of the existing infrastructure. Further, LRIC's adoption in the UK has triggered a wide review of transmission and distribution pricing in countries including Brazil, Ireland, India and China. It also led to the establishment of the IEEE International Working Group on Network Charging, chaired by Li (Bath). Many of LRIC's key researchers at Bath have subsequently taken key roles in network planning and pricing in UK and international industry.

2. Underpinning Research

Key researchers: Prof F Li (Bath 1997 – date), Prof D Tolley (Visiting Professor) and Prof N Padhy (Visiting Researcher sponsored by the Indian Government). PhDs/PDRAs at Bath: Dr H Heng, Dr C Gu, Dr S Latsky, Dr B Li, Dr Y Zhang, Dr E Matlosze, Dr J Wang and Dr B Kuri.

The introduction of renewable energy is a key step towards meeting the UK's binding commitment to reduce its CO_2 emissions by 80% by 2050, relative to the 1990 level. Achieving this will require that a significant amount of renewables be connected to the electricity distribution system, resulting in additional and substantial network investment - *unless those locations can be identified where renewable generators can be connected at the least cost*. The Distribution Network Operator companies (DNOs) are responsible for distributing electricity from generators to residential and commercial properties, but have no control over the location and size of prospective generators, except through the use of *network charges*. Prior to 2008, the UK's six DNOs employed flat-rate network charging schemes that effectively ignored both the location *where* electricity was generated and *how* it was distributed to the customer. Generation companies thus had no incentive to locate their generators closer to load centres to minimise network costs. However, electricity distribution costs are very significant and account for ~ 21% of UK electricity bills, with some £6 billion of network investment needed from 2010 to 2015. Industry regulator Ofgem recognised that flat-rate charging poses a major barrier to the cost-effective integration of renewables, so in 2005 it published a consultation document calling for a structural change to the charging regime (https://www.ofgem.gov.uk/ofgem-publications/44442/10763-13505.pdf).

In response to this call, Bath collaborated with Ofgem and Western Power Distribution to develop the LRIC economic charging methodology that enables DNOs to provide, for the first time, financial incentives to guide generators to connect at low-cost locations. Bath's LRIC defines the relationship between a ***location*** in an existing network and the ***cost*** of integrating renewable generation at that location [1, 2]. Bath's LRIC can handle practical distribution systems of more than 2,000 connection points and produce long-run predictions of investment cost in a fraction of the time of traditional approaches. It is thus a sophisticated yet practical mechanism for evaluating these long-term network costs. Unlike traditional approaches that rely on detailed and extensive system simulation for evaluating future network costs, Bath's LRIC employs a bespoke set of analytical equations that implicitly integrate the utilisation of all network components and the distances from the generators to consumers. Critically, ***this directly links the impact of an individual generator connection to future investment costs*** [1, 2]. The use of LRIC thus makes

it possible for DNOs to assess the impact on future investment costs of connecting generation at each network location. This enables DNOs to set cost-reflective and justifiable network charges, thus providing economic incentives to guide generators to the locations in the system offering the greatest long-term benefits [3].

The LRIC methodology was initially developed through direct industrial funding from Bath's local DNO, Western Power Distribution, and the industry regulator, Ofgem. It has since been substantially enhanced through funding from EPSRC (Advanced Research Fellowship, UK-China Smart Grid OPEN) and industry (Northern Powergrid, Npower and Centric) [4−6]. Continuing developments are funded by a Royal Society Wolfson Merit Award (Li, 2013-2018) and three large (each > £1 million) EPSRC funded bi-national projects: i) UK/China Smart Grid OPEN (Jenkins, Li *et al*. 2013-2016), ii) UK/China Smart Electric Mobility (Strbac, Li *et al*., 2013-2016) and iii) UK/India Smart Grid with Energy Storage HEAPD (Li, Jenkins *et al*. 2014-2017).

3. References to the Research

1) *****F Li and D Tolley, "Long-run incremental cost – pricing based on unused capacity", IEEE Transactions on Power Systems, vol. 22, no. 4, pp. 1683 – 1689, 2007. DOI: 10.1109/TPWRS.2007.908469.
2) F Li , "Long-run marginal cost pricing based on network spare capacity", IEEE Transactions on Power Systems, vol. 22, no. 2, pp. 885-886, 2007. DOI: 10.1109/TPWRS.2007.894849.
3) *****F Li and D Tolley et al, "Framework for Assessing the Economic Efficiencies of Long-run Network Pricing Models", IEEE Transactions on Power Systems, vol. 24, no. 4, pp. 1641-1648, 2009. DOI: 10.1109/tpwrs.2009.2030283.
4) *****H Heng, F Li, and X Wang, "Charging for Network Security Based on Long-Run Incremental Cost Pricing", IEEE Transactions on Power Systems, vol. 24, no. 4, pp. 1686-1693, 2009. DOI: 10.1109/tpwrs.2009.2030301.
5) F Li, N.P. Padhy, J Wang and B Kuri, "Cost-benefit reflective distribution charging methodology", IEEE Transactions on Power Systems, vol. 23, no. 1, pp. 58-64, 2008. DOI: 10.1109/TPWRS.2007.913201.
6) C Gu, F Li and Y Song, "Long-run Network Pricing to Facilitate Users' Different Security Preference", IEEE Transactions on Power Systems, vol. 26, no. 4, pp. 2408 – 2416, 2011. DOI: 10.1109/TPWRS.2011.2153215.

***** denotes references that best indicate the quality of the research.

4. Details of the Impact

Impact on Policy: After three years of industry-wide debate (2005–2008), Ofgem concluded, *"We believe LRIC, which is based on incremental cost, is the better foundation for pricing method with the objective of promoting more efficient network development to meet customer needs*" [a]. Ofgem consequently in 2008 **required** all DNOs in the UK to adopt LRIC and, in reaching this decision, sought views from all stakeholders. For example, Northern Powergrid (formerly CE Electric) strongly supported the move, stating that LRIC, "*is the best methodology to adopt as it most closely aligns to, and provides a programmatic balance of, the principles that have been developed",* and, further, that it *"provides the purest economic signals"*, [a]. In summary, **policy debate has been stimulated** and **policy decisions have been informed by research evidence**.

Impact on Industrial Practice & Standards: Bath's local DNO, Western Power Distribution, implemented the LRIC methodology for their extra high voltage (EHV) distribution system in April 2007. Following Ofgem's 2008 decision for its adoption as a licence obligation, LRIC was subsequently developed into a common methodology by the industry and in April 2011 it was adopted by the three remaining DNOs for their EHV systems in England and Wales. All four DNOs have confirmed this adoption, a typical statement being *"UK Power Networks have implemented the version of the EHV Distribution Charging Methodology (EDCM) which utilises the LRIC pricing approach as originally developed for Ofgem by Bath University. The EDCM is used for the calculation of charges in all three of our licenced areas including the East England, South East England and London."* [b]. In summary, through LRIC, industry's **professional standards, have been informed, improved processes have been adopted and, professionals have used research findings in the conduct of their work**. In addition, Bath has provided technical support to industry's adoption of LRIC through consultancies [c], thus **the efficiency of providing a**

professional service has been improved. Over time, the adoption of LRIC will reduce the investment required to accommodate the anticipated dramatic expansion of low-carbon technologies [d] and thus lower the cost of low-carbon transition. Bath's research thus allows DNOs to take the lead in combatting climate change and helps the UK meet its CO_2 emissions targets.

The Development of Policies and Services of Benefit to the Developing World: The development and implementation of Bath's LRIC methodology for distribution networks has stimulated debate and resulted in **benefits for countries in the developing world** - and in particular Brazil, India and China. The Brazilian distribution charging structure reform was influenced by Bath's research through Prof Li's participation in the International Seminar on Electricity Tariff Structure organised by the Brazilian energy regulator, ANEEL, in 2009 [e], through in-depth discussion with their tariff design team [f] and through collaboration with their lead scientist for network charges [g]. This subsequently led to the establishment of the IEEE Power and Energy Society International Working Group (IWG) on Network Charging chaired by Li (Bath) [h]. Through this IWG, LRIC has received significant interest from Brazil, Germany, Demark and India, which has, in turn, had a major impact on the research work's focus and direction at Bath and stimulated further research.

The impact on India has been through a UK/Indian Scientific Seminar held in Jaipur, February 2013. Bath led the UK delegation and used the opportunity to explore with leading Indian power industries and academics new tariff structures that are both economically efficient and socially acceptable [i]. This event was co-sponsored by the Departments of Business Innovation and Skills (UK) and Science and Technology (India). It has led to a £2 million UK/Indian consortium project led by Bath and IIT Roorkee in Smart Grid with Energy Storage (EPSRC/DST-HEAPD). In April 2013, Bath was invited by the China National Development and Reform Commission (Beijing) to disseminate the UK's network charging structure and presented a report documenting its evolution as part of China's international review to support its electricity market reform.

Many of Bath's PhDs and PDRAs have gone on to take roles in network planning and pricing in the UK and internationally, including Scottish & Southern Energy, UK (H Heng and B Kuri) and The State Grid Corporation, China (J Wang, B Li, Y Zhang). Through this pathway, **highly skilled people have taken up specialist roles that draw on their research**.

In summary, this research has had a major impact on government policy, which has fed through industrial practice and standards to result in societal, economic and environmental benefits.

5. Sources to Corroborate the Impact

a) Ofgem 2008 Decision Document 'Delivering the Electricity Distribution Structure of Changes Project', Section 2.29, page 17. https://www.ofgem.gov.uk/ofgem-publications/44256/decision-document-1-october-2008.pdf.
b) Email from Income Pricing Manager, UK Power Networks, 18 October 2013.
c) Northern Powergrid (former CE Electric), "Network charges for Yorkshire distribution area", F Li, £70k, 2008-2008.
d) Ofgem report, F. Li, D. Tolley, N. Padhy, J. Wang, "Network benefits from introducing an economic methodology for distribution charging", January 2006. https://www.ofgem.gov.uk/ofgem-publications/44386/12617-1206a.pdf.
e) International Seminar on Electricity Tariff Structure, ANEEL, 17th/18th June, 2009, http://www.aneel.gov.br/siet/index_eng.htm.
f) Email from ANEEL for meeting with their tariff design team.
g) F Li and J W Marangon Lima, "Micro-generation: Potential, Impacts and Network Charge", Invited panel paper, IEEE Power Engineering Society General Meeting, Paper 08GM1519, Pittsburgh, July, 2008.
h) IEEE Power Engineering Society (PES), Power System Economic Subcommittee, Network Charging Working Group, http://sites.ieee.org/pes-ses/working-groups-and-task-forces/wg-on-network-charging/
i) Award letter for International Scientific Seminar India-UK on "Economically and Socially Efficient Network Pricing for Smarter Distribution Grids", October 2012.