Institution: University of Strathclyde

Unit of Assessment: B12 - Engineering

Title of case study: Economic and environmental benefits from widespread adoption of active power network management scheme

Period when the underpinning research was undertaken: 2003-2008

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:**
Graham Ault Robert Currie	Professor Research Fellow	01/11/1998 - 30/06/2016 01/04/2006 - 31/08/2008

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

Is this case study continued from a case study submitted in 2014? Yes

1. Summary of the impact

Research into active power flow management undertaken at the University of Strathclyde resulted in the successful delivery of an active network management scheme on the Orkney Islands in 2009 and a spin-out, Smarter Grid Solutions Ltd. Since August 2013, Smarter Grids Solutions has received GBP40,200,000 in revenue and grown their connected generators list to approximately 450MW. The technology has been utilised by leading power network companies to connect renewable energy generators in the UK, US and Europe, with ongoing projects globally, resulting in cheaper and greener energy available to customers, more efficient and flexible network operation, and cost savings for power generation companies and utility customers. All 6 UK distribution system operators have implemented active network management, with consistent expansion and investment in the technology since August 2013.

2. Underpinning research

This research was undertaken in the context of the growth of renewable generation in the UK and the barriers to its connection to the power system including overcoming network capacity constraints, which became the focus for this research. Ault and Currie collaborated with Scottish and Southern Energy Power Distribution Ltd (SSEPD; now Scottish and Southern Electricity Networks) to define the active power flow management problem, and design a management scheme that would allow for integrating renewable energy generation and reducing electrical losses. The researchers established the conceptual design for an active power flow management approach based on measurement of circuit power flows and the regulation of wind farm power output to relieve network constraints. This was based on methods to calculate the wind generation constraints and economic feasibility of wind power in such a scheme [**R1**]. The wind generation (later generalised to any type of generation or electricity demand) constraint assessment enables a time series of electrical demand and generation (in half-hourly or higher resolution) to be assessed over a significant assessment window (e.g. years) to quantify the number of constraint periods and the total constraint energy volume for one or more generators. The economic impact of loss of generation revenue from energy sales and any renewable certificates or incentives can then be calculated. The initial research resulted in the core concept for Active Network Management (ANM) with the Orkney power network. The core research contributed an ANM requirements specification (including functional and non-functional elements), algorithms for control (including identification and resolution of multiple power circuit constraints) and a conceptual design (including measurement, communications, control hardware and software) for a deployable ANM system. The project was a significant step towards a deployable ANM solution based on underpinning power system and control research. The research also provided the necessary technical detail to allow discussion of the implementation of ANM concepts within the industry.

A further core research challenge tackled was a method for calculation of appropriate operating margins for an ANM scheme. This is important as operating margins that are too narrow present power network security risks while margins that are too conservative and wide limit access to the available network capacity for power generators. The research presented a method of calculating multiple operating margins that could be applied within an ANM scheme [**R2**]. The practical implementation of an ANM scheme requires that a power network is organised into different zones

of control and the research established the method for identifying these zones of control with reference to the identification of all possible network constraint locations. This approach was embodied in a patent [**R3**, **R4**].

3. References to the research (Strathclyde affiliated authors in **bold**)

R1 **Currie, R.A.F.**, **Ault, G.W.**, **McDonald, J.R**. (2006) Methodology for determination of economic connection capacity for renewable generator connections to distribution networks optimised by active power flow management. *IEE Proceedings-Generation, Transmission and Distribution, 153(4)*, 456 – 462. https://bit.ly/3ralUB2 [Available from HEI on request]

R2 **Currie, R.A.F.**, **Ault, G.W.**, **Foote, C.** and **McDonald, J.R.** (2007) Active power-flow management utilising operating margins for the increased connection of distributed generation. IET Generation, Transmission and Distribution, 1(1), 197-202. https://bit.ly/2OVPlKf [Available from HEI on request]

R3 GB Patent No. GB2460504 'Active Network Management Scheme' (Zones). Filed November 2008, Granted December 2009. https://bit.ly/3lD7Y1u

R4 GB Patent No. GB2476396 'Active Network Management Scheme' (Triggers). Filed November 2008, Granted December 2011. https://bit.ly/3lLiOmg

Notes on the quality of research: R1 and **R2** were peer-reviewed ahead of publication. The underpinning body of research was supported by GBP246,295 research funding based on the researchers' expertise (e.g. J.R. McDonald and G.W. Ault. 'Facilitate Generation Connections on Orkney by Automatic Distribution Network Management', June 2003-April 2004, GBP116,100 to Scottish Hydro Electric Power Distribution Ltd. (Strathclyde: GBP58,000)).

4. Details of the impact

The research undertaken at the University of Strathclyde between 2003 and 2008, in close collaboration with Scottish & Southern Energy Power Distribution (SSEPD), resulted in a spin-out, Smarter Grid Solutions Ltd, to commercialise the research [**S1**]. From 2009, SSEPD started connecting additional wind generation to the Orkney power system under the ANM scheme with Smarter Grid Solutions, with reinforcement deferral savings of GBP30,000,000 from ANM scheme go-live. Smarter Grid Solutions Ltd continue to be at the forefront of advising power companies on ANM technology and this impact on design and investment policy is a direct result of the research. Specifically, since August 2013, the research has:

- Enabled the growth and commercial success of Smarter Grid Solutions Ltd;

- Increased the number of clean energy assets connected to the grid in globally, resulting in cheaper and greener energy available to customers and cost savings for power generation companies;

- Informed the investment strategy and planning of distribution network and system operators in the UK, further supporting the expansion of clean energy.

Enabling the growth and commercial success of Smarter Grid Solutions Ltd.

Smarter Grid Solutions Ltd (SGS) grew substantially from formation in 2008 with total revenues to the end of March 2013 standing at GBP6,100,000 [**S1**]. By March 2020, the company's annual revenue had grown to GBP10,040,000, with a total revenue since August 2013 of GBP40,200,000 [**S1**]. As of 31st July 2020, SGS employs 75 FTE staff, based in Glasgow, New York and California [**S1**]. Director and Co-founder of SGS confirmed the importance of the underpinning research for the company's business offer:

'The ANM scheme marketed by Smarter Grid Solutions, based on the original collaboration between the University of Strathclyde and SSPED, enables our partners to design and implement solutions to enable connection of Distributed Energy Resources (DER), whilst maximising network efficiency and maintaining network reliability... We now have an enviable track record with the leading innovator companies, covering all types and sizes of DER, based on the proven value of this technology.' [**S1**]

Since August 2013, SGS has expanded its original product, AMN 100, into two products – AMN Strata and AMN Element. Both products continue to be based on the fundamental research into

ANM conducted at Strathclyde and were further informed by ongoing collaboration with current Strathclyde researchers [S1]. The Director of SGS highlights how this collaboration '*allows us to maintain our competitiveness and continually increase our business offer*.' [S1] SGS has invested around GBP25,000,000 in product development based on the research, and received over GBP3,000,000 in external investment to further develop the products in 2017 [S1]. According to the Director: '*This level of investment is further evidence of the value of Active Network Management to the renewables energy sector. The application of ANM technology in our products enables our customers to develop and operate their networks more efficiently and flexibly as required and incentivized by industry regulators*.' [S1]

Increasing the number of clean energy assets connected to the grid globally

With SGS having proven the value of the technology since its establishment, more and more power generation and distribution companies are adopting ANM as part of their operational technology to complement existing systems. SGS's connected generators list has grown to approximately 450MW as of July 2020, with contracts with distribution network operators to connect over 1GW in 2021 [S1]. The operational systems list, using products with the Strathclyde IP, currently includes the UK, US and Europe [S1]. Examples of the connections enabled by SGS, resulting in cheaper and greener energy available to consumers and cost savings for power generation companies, are presented below.

Scottish Power Energy Network, 3,500,000 customers in the UK

Scottish Power Energy Network (SPEN) partnered with SGS on 'Accelerating Renewable Connections', a four-year project which concluded in 2016, and committed to implementing ANM in their 2015-2023 Business Plan [S2]. Since August 2013, they have connected around 160MW of renewable energy in East Lothian, Scotland, using ANM, providing enough energy to power 160,000 homes [S2]. The Dunbar Energy Recovery Facility is an example of AMN implementation, with SGS enabling the provision of 258GWh of renewable energy direct to the National Grid from an existing waste treatment hub in East Lothian [S2]. This energy output is the equivalent of 39 wind turbines, and is enough to continuously power over 70,000 homes [S2]. SPEN's analysis of the 'Accelerating Renewable Connections' project estimates that the savings in connection and network reinforcement costs from the application of ANM are in excess of GBP20,000,000 [S2]. In June 2020, SPEN reaffirmed their commitment to using ANM in their Distribution System Operator (DSO) Strategy '*to get the best out of our existing network capacity, helping to keep bills low for customers and facilitate the drive to a more flexible, smart network required for NetZero.*' [S2]. SGS have been engaged to deliver a wider network rollout of ANM with a new centralized system due to become operational during 2021, with several hundreds of MW of renewable generation connections in Dumfries and Galloway, Scotland, and North Wales expected thereafter [S2].

UK Power Networks, 8,300,000 customers across the East and South East of England

Similarly UK Power Networks (UKPN) partnered with SGS on their 'Flexible Plug & Play' project (2011-2014), which demonstrated the value of adopting the approach for the company, who subsequently committed to implementing an '*industry-leading*' ANM system in their 2015-2023 Business Plan [S3]. This commitment has recently been accelerated, such that UKPN are now deploying the system two years ahead of schedule to help facilitate flexible renewable energy generation connections. Since defining the Business Plan, UKPN has connected over 120MW of solar, wind and biofuel generators in East Anglia, England, providing energy to power approximately 120,000 homes [S3]. UKPN's system, powered by SGS software, was described by respected independent American consultancy group Wood Mackenzie as '*amongst the world's most advanced*' and has delivered over GBP70,000,000 in savings for energy generator customers [S3]. Flexibility contracts are now being introduced as a matter of standard practice for UKPN as part of their transition to DSO, so that all suitable newly connected generators will have the opportunity to benefit from ANM [S3]. This rollout of flexible generation connections is expected to result in 2.5GW of generation connections and is the fastest and largest enterprise rollout of this technology [S3].

SSE Enterprise, part of energy supplier SSE, 3,600,000 customers in the UK and Ireland

SSE Enterprise is responsible for providing SSE with innovative solutions for their energy infrastructure in the UK and Ireland, and adopted SGS's ANM technology to support increased

connection of renewable and other clean, distributed, flexible energy resources to the grid and market [**S4**]. In particular, SSE Enterprise have used ANM Strata to connect their customer's energy assets to their systems and markets [Text removed for publication] and have ongoing projects to connect generators at commercial and industrial customer sites, business and university campuses and local authority buildings [**S4**]. Confirming the benefits of this technology, the Director of SSE Enterprise stated: '*[it is] enabling us to meet our green ambitions, serve our customers well, keep our energy prices low and meet our business objectives… SGS's expertise in control and aggregation has been invaluable to help us create a platform that operates as we need it to.*' [**S4**]

AVANGRID, 3,100,000 customers throughout New York and New England, US

AVANGRID, part of the Iberdrola Group, partnered with SGS in 2015 to develop and conduct demonstration projects as part of the New York Reforming the Energy Vision policy [**S5**]. The resulting project - Flexible Interconnection Solutions (FICS) – was designed to demonstrate a process for energy generation developers and AVANGRID to curtail generation (i.e. flexible capacity) rather than conventionally reinforcing the grid (i.e. firm capacity). This approach maintains the viability and benefits of renewable development while ensuring the grid remains within service requirement specifications, such as voltage and equipment thermal limits, using SGS ANM technologies [**S5**]. This solution encourages the development of distributed energy resources in the New York system and market. AVANGRID is leveraging this work to help meet the Reforming the Energy Vision policy goals of increasing distributed grid connections, reducing electricity costs and improving the environment [**S5**]. In the future, FICS has the potential to enable additional DER interconnections that would not be viable under the current model [**S5**].

Enzen Global Solutions Energy Consultants

In 2020, SGS partnered with Enzen Global Solutions energy consultants to implement ANM in several global regions (notably Australia and India) and, in September 2020, announced a deployment project in the Southern Indian State of Tamil Nadu [**S6**]. This area has a high proportion of wind and solar renewables, and ANM will be used to minimize renewable energy curtailment and improve system balancing. This project is the first of its kind in India and has a huge potential for scaling up in other parts of the country. Ultimately, this project will result in cheaper, quicker, and more flexible energy generation connections and will further advance India's clean energy goals [**S6**]. Speaking in media coverage at the time, the Vice President of Enzen Global Solutions stated: '*Enzen believes in leveraging best-in-class technology from across the globe to meet local needs, and that's why we're collaborating with Smarter Grid Solutions. The pilot is an important step in maximising renewable energy uptake by the grid, and realising the full benefit of renewable energy for electricity companies, project developers and communities.*' [**S6**]

Informing the investment strategy and planning of distribution network operators

The successful deployment of ANM technology on Orkney gave confidence to power companies to invest in further deployments of this technology under innovation funding (i.e. Low Carbon Network Fund, Network Innovation Competition and Network Innovation Allowance) and to include ANM technology in their investment plans for the period 2015-2023 under the RIIO price control mechanism [**S2**, **S3**]. This uptake of ANM was highlighted in the UK Government's 2017 Smart Systems and Flexibility Plan as addressing the action on Distribution Network Operators to '*make more efficient use of new technologies, providers and solutions'* [**S7**]. The Plan noted: '*It is critical that DSO [Distribution System Operators], transmission owners (TOs) and the SO [System Operator] develop timely and appropriate reforms to the way they plan, operate and engage with one another and customers, in order to manage the networks more efficiently and minimise whole system costs… We are seeing progress now (such as growth in active network management and greater coordination), but further demonstrable progress must be made.*' [**S7**]

In their recently published DSO strategies (2017-2020), all 6 UK Network Operators committed to expanding ANM as a key aspect of their development plans [**S8**]. As highlighted above, SPEN and UKPN have integrated ANM into their standard practice [**S3**, **S4**, **S8a**, **S8b**]. Scottish and Southern Electricity Networks (SSEN), as a collaborating partner in the Orkney project, specifically highlights the work of SGS and the University of Strathclyde in their DSO update: '*SSEN pioneered flexible connections alongside Smarter Grid Solutions and the University of Strathclyde in Orkney*'.

[**S8c**] By 2019, SSEN had made ANM available to all generator customers in SSEN distribution areas and had delivered over 200MW in flexible connections [**S8c**]. Through their ANM Centralisation project, SSEN invested GBP1,800,000 in a new ANM system to support this roll-out [**S8c**]. In their DSO strategy published in February 2020 [**S8d**], Western Power Distribution, who have been rolling out ANM since 2016, stated their intention to '*Roll out Active Network Management across entire network by 2021, with expanded connections options available for customers allowing them to get quicker and cheaper access to the network*' [**S8d**]. Electricity North West listed ANM as an '*enabler*' and committed to implementing a whole system ANM suite to allow dispatch of flexible resources and help manage the flow of energy, highlighting '*whole system benefits through coordination between transmission and distribution requirements delivering efficient network solutions and striking the right balance between new build and flexible solutions.*' [**S8e**] Northern Powergrid, who already have one live ANM zone in the North of England and 433MW of contracted flexibility across three other ANM zones, also included ANM as a '*key enabler for decarbonisation*' stating: '*through ANM, we are able to actively manage exports from generation customers in order to provide them with cost-effective connections to the distribution network. This scheme is ground-breaking for us, as it is our first replicable scheme, meaning that we now have a standardised solution that we can roll out anywhere this situation occurs on our network.*' [**S8f**]

Through the commercialisation of ANM products sold by SGS, the Strathclyde research developing ANM has been picked up by leading distribution network operators to provide cleaner and more efficient energy, and has enabled them to adapt to Government regulations and recommendations. Summarising the benefits of partnering with SGS, Head of Smart Grid Development at UK Power Networks stated:

'By increasing the connection of renewable energy resources, we are able to meet our network development, customer connections and clean energy goals, improve the flexibility and efficiency of our network, and reduce the costs of network connection for energy generators as well as our customers… we consider 'efficient and effective' networks and being 'net zero ready' to be key innovation themes that support our business offer and Smarter Grid Solutions enables that.' [**S3**]

5. Sources to corroborate the impact

S1 Corroborating statement from Executive Director and Co-Founder, Smarter Grid Solutions (19/11/2020).

S2 Corroborating statement from Network Planning & Regulation Director, Scottish Power Energy Network (12/03/2021).

S3 Corroborating statement from Head of Smart Grid Development, UK Power Networks (12/03/2021).

S4 Corroborating statement from Director of Digital Services and Strategy, Distributed Energy, SSE Enterprise (09/03/2021).

S5 Corroborating statement from Lead Analyst, Smart Grids Innovation, AVANGRID (16/03/2021).

S6 Corroborating statement from Vice President & Global Head of Applied Research and Collaboration, Enzen Global Solutions Ltd. (09/03/2021) and appended press release.

S7 HM Government & Ofgem. Upgrading Our Energy System: Smart Systems and Flexibility Plan. https://bit.ly/38CFaS8

S8 Collated DSO Strategies

    a. Scottish Power Energy Network. Distribution System Operator Strategy Summary. June 2020. https://bit.ly/3naUCcD

    b. UK Power Networks. Future Smart, A smart grid for all: Our transition to Distribution System Operator. 2017. https://bit.ly/3n8flhf

    c. Scottish and Southern Electricity Networks. Delivering DSO: A Progress Update. November 2019. https://bit.ly/3451AIL

    d. Western Power Distribution. DNO transition to DSO. February 2020. https://bit.ly/3qMjhGR

    e. Electricity North West. DSO Strategy: Consultation. July 2020. https://bit.ly/3m8DbIy

    f. Northern Powergrid. Distribution System Operator: Development Plan. October 2019. https://bit.ly/3qUgaNh