E. S. Cornwall Memorial Scholarship

Sixth Quarterly Report

Commonwealth Edison

1st February 2016 – 6th May 2016

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17/06/2016

Disclaimer

This report provides a candid assessment of the author's experiences, drawing comparisons to the Australian electricity supply industry. Statements and material contained within this report (except where explicitly referenced) are the expressed opinion of the author and do not that of any person or organisation associated with the author. Any reproduction or referencing of this report should reflect this.

Acknowledgements

The author of this report acknowledges the support of Commonwealth Edison and its employees. Without their assistance and willingness to share knowledge this report would not have been possible. In particular, the author would like to thank: Daniel Gabel (Manager of Interconnection and System Studies, Commonwealth Edison), Joe Svachula (Vice President of Smart Grid and Technology, Commonwealth Edison), Shay Bahramirad (Director of Smart Grid and Technology, Commonwealth Edison), Manuel Avendano (Manager of Emerging Technologies, Commonwealth Edison), all members of the Smart Grid and Technology team (who are too many to name), and Prof. Simon Bartlett (Australian Chair in Electricity Transmission, University of Queensland).

The author would also like to thank: the E. S. Cornwall Memorial Scholarship and its Board for the personal, professional, and technical development opportunity that this scholarship affords; his family (Heather, Allan and Hayley) for their ongoing support and encouragement; and his friends and colleagues, both old and new.

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1 Glossary, Abbreviations & Definitions

Table 1: List of acronyms, abbreviations, and technical terminology

Terminology / Acronym / Abbreviation	Definition
CCERI	(Massachusetts) Community Clean Energy Resiliency Initiative
CEC	California Energy Commission *California's state energy policy and planning agency*
CISO	California Independent System Operator *California's independent, not-for-profit transmission system operator*
ComEd	Commonwealth Edison (Company)
CPUC	California Public Utilities Commission *California's state regulator for the electrical, gas, water, and telecommunications industries*
DEEP	(Connecticut) Department of Energy and Environmental Protection *Connecticut's state government department for natural resources and environmental protection and the regulator of public utilities*
DER	Distributed Energy Resource
DG	Distributed Generation
DNO	Distribution Network Operator
DoD	(US) Department of Defence *The USA's Federal Government department that is responsible for managing all matters concerned with national security and the armed forces*
DoE	(US) Department of Energy *The USA's Federal Government department that is responsible for managing policies relating to nuclear safety and the energy sector*
EPRI	Electric Power Research Institute *A not-for-profit research organisation largely funded through investments from organisation in the electricity industry*
ERB	(New Jersey) Energy Resilience Bank
GE	General Electric
GE	General Electric
ICC	Illinois Commerce Commission *The state government appointed tribunal that is responsible for regulating utilities in the state of Illinois*
IOU	Investor Owned Utility
MW	Mega-Watt
NYSERDA	New York State Energy Research and Development Authority *A public benefit corporation in the state of New York that is responsible for encouraging research and development in renewable generation and energy efficiency*
PQ	Power Quality
RMS	Root Mean Squared
SEL	Schweitzer Engineering Laboratories
USA	United States of America
USD	United States Dollars

2 Executive Summary

Distributed generation, microgrids, and power quality are three areas of growing interest within the electricity industry, with each topic having a direct connection to, and impact on the remaining two. Distributed generation, particularly renewables, are seen as a key component of the push to improve energy sustainability; however, the deployment of distributed generation can have a significant, and possibly negative impact on local power quality. Similarly, microgrids, which are seen by many in the USA as a pathway to improving electrical grid security and resiliency, depend on high-levels of distributed generation penetration for their viability. Microgrids also offer improved monitoring and control of the distribution grid that enables more granular monitoring and control of power quality. Ultimately power quality is a fundamental component of the service provided by transmission and distribution utilities. As such it is a core consideration in the deployment of distributed generation and microgrids. It is these three topics that are the focus of discussion in this report.

In particular, this report discusses:

- The content of a white paper titled, “The USA’s Microgrid Landscape: Ownership Models, Policies, Incentive Schemes, and Deployment,” which I co-authored, and that examines frameworks, incentive schemes, and existing deployment of microgrids within the USA;
- Finalization of the distributed generation hosting capacity assessment tool that I developed over my nine months with ComEd; and
- Drafting of a System Power Quality Strategy that will outline ComEd’s approach to identifying, prioritizing, and mitigating power quality issues, and more specifically a discussion paper that I authored that sets the foundation for this strategy.

These three areas were the core focus of my work over the last three months.

As this is my final quarterly report, I have now completed my placement with ComEd and my tenure on the E.S. Cornwall Memorial Scholarship. I now look forward to returning to Australia where I will resume employment with Ergon Energy as a Substation Maintenance Standards Engineer based in Brisbane, Queensland.

3 Introduction

This report builds on my previous quarterly reports undertaken on the E. S. Cornwall Memorial Scholarship. For more information on past reports see http://escornwall.com.au/index.php/category/study-topics/optimise-expenditure-on-asset-management/.

3.1 Motivation

Australian Transmission and Distribution Network Operators (TNOs and DNOs) are under continual pressure to provide a more economical, efficient network while ensuring the reliability and security of supply to consumers. Recent years have seen the prevailing perception of electricity network service providers as over investing, building "gold-plated" networks. This has been compounded by a circa 70% increase in the average cost of residential electricity from 2008 to 2012, with 51% of this price being made up of network charges [1].

During the same period advances in distributed generation (DG) and its affordability (through incentives and economies of scale) have placed significant pressure on the traditional operating model of TNOs and DNOs. If TNOs and DNOs are to remain relevant players in the electricity supply chain they will have to adapt to the changing network environment and increasingly competitive market in all facets of their business. One area that will be heavily impacted by this drive for efficiency and change will be asset management, the focus of my placement on the E. S. Cornwall Memorial Scholarship.

3.2 Area of Research

During my tenure on the E. S. Cornwall Memorial Scholarship I will explore ways of optimising capital and operational expenditure in asset management. In particular, I am interested in understanding how:

- International best-practice asset management techniques, such as the Publicly Available Specification (PAS) 55 (PAS55:2008) and the recently published International Standards Organisation (ISO) 55000 (ISO55000:2014), can be used to drive efficiency in asset management.
- Improvements in data availability and analysis can be used to better understand network and asset performance, subsequently driving more informed and better value investment in assets.
- New technologies can be utilised within the network to improve network performance as an alternative to, or means of deferring expensive network augmentations.

I will also gain exposure to leading business practices, systems, technologies, and research that may fall outside of these core areas. Where this occurs I will provide information as an appendix to my scholarship reports.

To achieve this body of research I am undertaking two, nine-month placements within:

- **UK Power Networks (UKPN)** – a DNO servicing the south eastern region of England in the United Kingdom; and
- **Commonwealth Edison (ComEd)** – a transmission and distribution network operator servicing the northern Illinois area in the USA.

This document is the sixth and final quarterly report to detail my placements on the scholarship. It covers the last three (of a total nine) months that I have spent at ComEd based in Oakbrook Terrace, Illinois. During this period, and for the majority of my placement with ComEd, I have been working within the Smart Grid and Technology team. In the last three months I have had three predominant focuses:

- Finalizing, documenting, and handing over the DG hosting capacity assessment tool that I have worked to develop over the past nine months. In particular, during this period I published

an internal paper documenting the system-wide hosting capacity assessment, co-authored a number of industry papers on this topic, developed technical documentation of the code, assisted in the development of a user interface for the tool, and provided training and handover for the work that I completed.

- Co-authoring a white paper titled "The USA's Microgrid Landscape: Ownership Models, Policies, Incentive Schemes, and Deployment" that provided an overview of the application of microgrids within the USA, including analysis of key state-level policies and incentive schemes around microgrids.
- Drafting a System Power Quality Strategy to set out a plan for ComEd to identify, prioritize, and address power quality (PQ) issues on their network, leveraging existing smart metering infrastructure and additional monitoring capabilities.

This report will cover this work in more detail.

4 Background

For an overview of:

- The electricity industry in the USA and Illinois, ComEd, its parent holding company Exelon Corporation, and the Smart Grid and Technology team see Section 4 of my Fourth Quarterly Report [2].
- Microgrids and the benefits that they provide, see Section 4 of my fifth Quarterly Report [3].

5 Placement Experience

This section provides an overview of work that I have completed, including lessons learned from my experience. It consists of three subsections that discuss: Microgrid activities within the USA, including microgrid ownership models; the finalization of my work on ComEd's distributed generation hosting capacity assessment tool, and the development of a system-wide power quality strategy for ComEd's distribution network. Where possible, I have drawn comparisons as to how my experience may be of value to the Australian electricity supply industry.

5.1 Microgrids

As part of my ongoing work around microgrids, this quarter I worked alongside my colleague Aleksi Paaso (Manager of Grid Strategy and Analytics, Commonwealth Edison), to author a white paper titled "*The USA's Microgrid Landscape: Ownership Models, Policies, Incentive Schemes, and Deployment"* that provided an analysis of key state-level policies and incentive schemes around microgrids. The following section discusses some of the research conducted as a part of this review, with a particular focus on microgrid ownership models and existing, state-level activity.

It is important to note that this section follows the four tiered definition of microgrids provided in Section 4.1.1 of my Fifth Quarterly Report [3], and paraphrased herein. Microgrids can be broadly classified as:

1. **Single customer microgrid**, that incorporates one customer (e.g. a data centre or commercial or industrial business) and embedded generation (typically a diesel generation).
2. **Partial-feeder or facility microgrid**, that incorporates multiple customers generally located in close geographical proximity (e.g. housing estates, small communities, military bases, or medical facilities) that may incorporate multiple distributed energy resources (DERs).
3. **Full-feeder microgrid**, that incorporates multiple customers over a more diverse area and utilizes distribution infrastructure (i.e. a distribution feeder) as the backbone for interconnection of multiple DERs.
4. **Substation microgrid**, that incorporates a large number of customers serviced by different distribution feeders, which provide the backbone for interconnection of multiple DERs.

5.1.1 Microgrid Ownership Models

Mirroring the diverse nature of microgrids, there are a number of different business models that may be applied to microgrid development, ownership, and operation. Broadly speaking ownership models for microgrids can be defined as private, independent, utility or hybrid ownership [5, 6, 7, 8]. Depending on the microgrid application, different ownership models will likely be more applicable. These ownership models are defined in more detail in Table 2.

Table 2: Defining microgrid ownership models

Ownership Model	Definition	Applicability
Private	A single party owns and operates the DERs and associated infrastructure required to sustain microgrid operation.	Single customer or small facility microgrid, where the private owner provides service within a clearly defined boundary, for the specific purpose of providing continuity of supply to their facility (e.g. a commercial building, or private facility).
Independent	An independent party owns and operates the DERs and associated infrastructure on behalf of one or more other parties.	Single customer or facility microgrid, where the customer(s) are located in close geographical proximity and within a clearly defined boundary (e.g. an industrial park, university campus, or military base).
Utility	The utility owns and operates the DERs and associated infrastructure on behalf of customers.	Large facility, full-feeder or substation-level microgrid, where the utility can leverage existing electrical infrastructure to service a number of diverse and independent customers.
Hybrid	Private or independent parties own and manage DERs with a direct interface to the utility that provides the associated infrastructure and overarching operation to ensure system stability.	Large facility, full-feeder or substation-level microgrid, where there is existing or additional investment in DERs from private and independent parties that can be leveraged alongside existing infrastructure to service a number of diverse and independent customers.

A common misconception is that these ownership models are equivalent and similarly scalable – this is not the case. As outlined in Table 2, single customer and partial-feeder or facility microgrids are better suited to investment by private entities or third parties, particularly where the electrical sub-systems are already owned by a private entity or third party (e.g. on the customer side of the point of connection). These applications are generally characterized by clearly defined and limited objectives that focus on providing a resilient supply to a small number of customers. More complex cases, such as large-facility microgrids and full-feeder or substation-level microgrids, are better suited to partial (i.e. hybrid) or full utility ownership, as these applications align more directly with, and are an extension of, the distribution function provided by utilities. In this instance, a distribution utility is able to leverage the existing distribution infrastructure, expertise and system capabilities to manage a diverse customer base and set of objectives. Moreover, in the case of larger, geographically dispersed microgrids it is not economically viable or efficient for third parties to replicate the systems, infrastructure, and expertise prevalent in utility organizations; nor is it permissible in many instances owing to protections established as part of a utility's franchise agreement.

For the hybrid ownership model, the additional capital made available by allowing third party investment in generation may aid in the proliferation of microgrids. However, such a model would require coordination of DER operation across the microgrid to ensure safe operation and stability of the microgrid, much in the way that the utility independently operates and manages the existing transmission and distribution grid. This would introduce multiple additional interfaces into this operational process (i.e. between the utility and participating third parties) and would significantly

complicate the operation of the microgrid, creating the opportunity for instability or mal-operation of the microgrid. Given this additional complexity, it would be necessary that clearly defined roles, liabilities, and responsibilities be developed for all participants engaged within a hybrid ownership arrangement. Moreover, a single entity representing the microgrid will likely be necessary to provide a consolidated, single point accountability for microgrid planning, operation, and maintenance even after the initial interconnection. This would add further administrative burden and associated cost to any hybrid ownership model when compared with the three other ownership models that have inherent single point accountability.

Figure 1 provides a graphical representation of the applicability of different types of microgrid configurations and their likely ownership models. It is important to note that isolated systems are those that operate in remote or isolated communities in locations where the cost of providing a grid connection is prohibitively expensive. These systems are sometimes referred to as microgrids; however, they lack one of the defining capabilities of a microgrid – the ability to connect and disconnect from the wider electricity grid. For grid connected systems, the two defining factors are: the number of users and the extent of microgrid boundaries. For these systems, it is likely that two ownership models will prevail:

1. For small, discrete systems, that service a limited number of parties, and where the system can be wholly encapsulated within a low voltage distribution network, privately owned or independent ownership will likely prevail. In this instance the objectives of the microgrid are selective and targeted, generally providing resiliency to customers who are able to fund the cost of microgrid development.
2. For larger, complex systems, that service a diverse range of customers, and where these customers are more loosely geographically located (i.e. within a large facility, community area, or region), utility or hybrid ownership will likely prevail. In this instance the utility can leverage existing infrastructure and expertise in a regulated environment to balance the deployment and operation of the microgrid in light of a multifaceted set of objectives on behalf of, and for the benefit of the wider public.

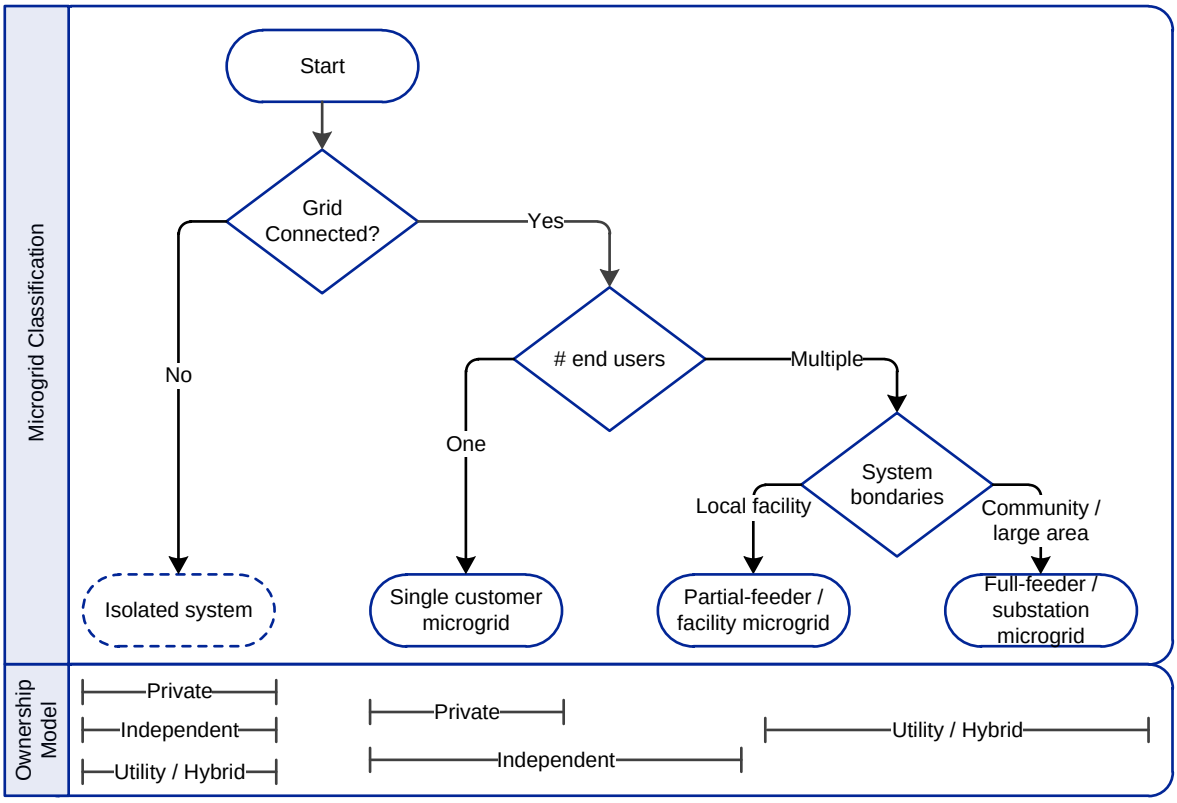

Figure 1: Classification of microgrids and ownership applicability

5.1.2 State-level Policies and Incentives

Within the USA, microgrids are receiving substantial attention, in part because of the possible environmental benefits, improved grid efficiency, and increased capability to incorporate distributed generation, but likely more so because of the added resiliency that they provide (as discussed in Section 4.1.2 of [3]). It is this resiliency of the electrical system, that is hard to measure or quantify, but that largely justifies the significant investment required to construct a microgrid. Particularly in light of the seemingly increasing severity and frequency of weather and climate related disasters[1] [9], and the threat of cyber or physical attack.

This importance was highlighted in the USA's Presidential Policy Directive 21 (PPD 21): Critical Infrastructure and Resilience [10] that identifies energy infrastructure (such as the electricity grid) as, "*…uniquely critical due to the enabling functions they provide across all critical infrastructure sectors*." The directive underscores that, "*Proactive and coordinated efforts are necessary to strengthen and maintain secure, functioning, and resilient critical infrastructure – including assets, networks, and systems – that are vital to public confidence and the Nation's safety, prosperity, and well-being."*

In light of this directive a number of states have begun developing or have already developed policies and incentive programs to encourage and support microgrid development; namely the states of California, Connecticut, Maryland, Massachusetts, New Jersey, and New York. For all of these states, excluding California, the development of microgrids holds particular importance, as they were all impacted by Hurricane Sandy[2]. As such, the majority of these state incentives are targeted at

[1] It is important to consider that this increasing trend of billion-dollar disasters is likely due, in part, to the increased exposure of people and infrastructure to these disasters as result of population growth and development.

[2] Hurricane Sandy (also called Super-storm Sandy) originated in the Caribbean Sea in late-October 2012, affecting a number of island nations in the Greater Antilles before traversing the east coast of the USA, crossing the coast in New Jersey. Sources put the estimated cost of Hurricane Sandy between (USD) $65 and $75 billion.

supporting critical infrastructure and emergency preparedness. The following subsections provide an overview of the microgrid funding mechanisms for each of the aforementioned states.

5.1.2.1 California

In July 2014, the California Energy Commission (CEC) published a competitive program opportunity notice (PON) for the demonstration of "secure, reliable, microgrids and grid-linked electric vehicles to build resilient, low-carbon facilities and communities" (PON-14-301), which is funded through California's Electric Program Investment Charge (EPIC)[3]. This award initially provided (USD) $26.5 million in funding, but was later increased to approximately (USD) $29.6 million in 2015, for projects in three specific areas. These projects related to the demonstration of:

1. Low carbon-abased microgrids for critical facilities;
2. High-penetration, renewable-based microgrids; and
3. Advanced, smart, bi-directional vehicle charging.

As is evident from these three target areas, the CEC is targeting projects and technologies that will have a significant impact on minimizing the carbon emissions of the supplied systems or developing enabling technologies (like bi-directional electric vehicle transfer).

As of September 1st 2015, the CEC had awarded funding to nine projects and matched funding for an additional eight projects. Of these 17 projects, eight related to microgrid development (project categories 1 or 2) and nine related to electric vehicle charging (project category 3). A summary of funding across these project areas is provided in Table 4. It is interesting to note from this summary that, although these microgrid projects comprised less than half of the total number of projects, the two microgrid streams attracted 87% of the overall funding offered. Moreover, of the eight microgrid projects, three were proposed by research entities (namely, universities), one by a utility (San Diego Gas and Electric), and four by private or independent parties.

Table 3: Summary of funding California Energy Commission's funding for microgrid and electric vehicle development (PON-14-301) [11]

Project Stream	Number of Projects	Funding Provided (USD, million)	Funding Percentage
1. Low-carbon microgrids for critical facilities	4	16.6	56%
2. Renewable microgrids	4	9.1	31%
3. Bi-directional electric vehicle charging	9	4	13%
Total	**17**	**29.7**	**-**

In addition to this incentive scheme, California already has a number of notable microgrids that service a range of public and private facilities; among these are the:

- **Borrego Springs Microgrid** – a utility-owned (San Diego Gas and Electric) microgrid that services the community of Borrego Springs, situated in southern California close to the border with Mexico. Borrego Springs is a remote community of approximately 4,354 people (334 commercial and industrial and 2,256 residential customers) that is serviced by an approximately 50km (30mi) long 69kV transmission line. The microgrid was constructed to provide increased flexibility and reliability to the system that supplies Borrego Springs; particularly in allowing for outages to maintain the 69kV transmission line. The microgrid has a combined distributed generation (rooftop solar PV and diesel) and energy storage capacity of approximately 4MW and is now being expanded to incorporate a 26MW solar PV plant and surrounding communities. [12, 13]

[3] EPIC is customer-funded grant that was established in 2011 and is targeted at encouraging research and development in technologies that will: improve the sustainability of the electricity sector, reduce energy costs, and improve safety.

- **Santa Rita Jail Microgrid** – a privately-owned microgrid that was developed in partnership with Chevron Energy Solutions. The Santa Rita Jail has the capability to house more than 4,000 inmates and has an average monthly peak load of approximately 2MW. The microgrid was developed to increase system reliability[4] (providing near perfect resiliency), particularly for a large prison facility where power outages can pose significant security threats, while also reducing loading on the distribution network. The microgrid has a combined distributed generation (diesel generation, solar PV, and fuel cell) and energy storage capacity of approximately 6.6MW. [14]
- **University of California San Diego Microgrid** – a university owned microgrid that services the 485 hectare (1,200 acre) university campus and its facilities. The university has a daytime population of approximately 45,000 and has a peak load of approximately 40MW, which is serviced from four 12kV substations located around the campus. The microgrid has been developed to provide a highly resilient supply for the university campus, while increasing sustainability and energy efficiency, and reducing energy costs and grid-dependence. It also operates as a test bed for new technologies and systems to be trialled in a microgrid environment. In total, the microgrid contains 42MW of distributed generation (solar PV, concentrating solar PV, combined cooling and heating plant, and cogeneration) and energy storage (thermal storage and fuel cells) that supply the energy needs of the university (in part or in full) on a daily basis. [15]
- **Camp Pendleton Microgrid** – a military microgrid that supplies the Camp Pendleton Marine Corps Base, which has a daytime population of approximately 100,000 people. The microgrid consists of four embedded microgrids and is designed as a modular and scalable system (termed “fractalgrid” design). The predominant focus of the microgrid is to provide a highly resilient supply for the military facility, but it is also operated to achieve carbon reductions (through renewable generation and reduced usage) and to manage loading on the utility feeder. Embedded within the facility is a total of 1.1MW of generation (solar PV, concentrating solar PV, and diesel) and energy storage (flywheel and battery) capacity. [16]

Funding for these microgrids has been sourced through a number of state (CEC), federal (Department of Energy (DoE) and Department of Defence (DoD)) and industry (utility, manufacturer, and private-investor) partners on a case-by-case basis.

In addition to California’s existing and established work around microgrids, the CEC, California Public Utilities Commission (CPUC), and California Independent System Operator (CAISO) is planning to develop a state-level microgrid road map [17]. This roadmap will provide a consolidated plan for the development, ownership, and regulation of microgrids within California, ensuring that future growth in microgrids is done in a controlled and sustainable manner.

5.1.2.2 Connecticut

In October 2012, the Connecticut Department of Energy and Environmental Protection (DEEP) Microgrid Program and Loan Program (termed the “Microgrid Program”) [18] was established with the aim of providing funding for distributed generation at critical facilities to improve resiliency during major weather events and other grid outages. To date this program has consisted of four stages:

1. **Feasibility assessment** – following its announcement, the program received 36 microgrid proposals, covering a diverse range of applications from small multi-kW systems providing supply to a single facility, to much larger, multi-MW systems supplying a number of private and public facilities. In February 2013, these applications underwent a feasibility assessment conducted in part by Connecticut’s two major investor owned utilities (IOUs): Eversource, and United Illuminating Company. From this assessment, 27 of the 36 applications were considered for pilot implementation.
2. **Pilot** – of the revised 27 applications a final nine were selected for pilot implementation in July 2013, with (USD) $18 million being shared amongst the successful applicants [19]. The pilot microgrids generally consisted of larger, partial-feeder microgrids that provided supply to a number of emergency services, schools, and disaster response facilities.

[4] Historically, the jail may be exposed to up to 15 seconds of power outage before the existing diesel generators were able to come online and supply the facility.

3. **"Round 2"** – In October 2014 an additional two microgrid projects were awarded a total of (USD) $5 million to establish a community and university microgrid (respectively).
4. **"Round 3"** – In November 2015 a call for proposals was issued for the third round of microgrid funding. Awardees will be allocated between (USD) $3 million to $5 million, with a total of (USD) $30 million in funding available. To date, no announcements have been made as to the successful recipients of this funding

5.1.2.3 Maryland

In February 2014, the Maryland State Governor announced the establishment of the Resiliency through Microgrids Task Force, which was established to explore and provide recommendations to remove legal, regulatory, technical, and financial barriers to the deployment of microgrids within the state. This task force released its findings report in June 2014 [20], which included 33 recommendations and conclusions across these four areas.

Among other things, the report recommends that, in the short-term, the state should pursue, "*utility owned, multiple customer, public purpose microgrids*," (i.e. utility owned microgrids) for uninterrupted electric service to critical community assets such as government facilities, community centres, commercial hubs, and emergency services. Establishing this capability will require that utilities could own and operate generation and distribution assets.

In the long-term, the report highlights that private or independent ownership (termed "new asset microgrids") or hybrid ownership (termed "local microgrid operators") may provide value, particularly introducing competition into the electricity distribution sector. However, the report also discusses the legal and regulatory issues associated with non-utility ownership of distribution assets. Indeed, the report explains that, under current legislation non-utility ownership of distribution is not feasible, namely due to the franchise rights[5] of distribution utilities and the challenges with regulation of non-utility owned microgrids, a consideration that holds true in many other states in the USA.

Moreover, the report recommends the development of suitable and sustainable cost recovery mechanisms to encourage investment in public purpose microgrid systems. Under Maryland's current tariff system there is limited capability (particularly for private or independent owners) to derive financial benefit from microgrid operation outside of the savings made through increased supply resiliency. The report suggests that tariff structures should be revised to provide aid in offsetting the cost of microgrid deployment, and emphasises the importance the microgrids be designed around applications that have "stackable" benefits (i.e. multiple, concurrently realisable benefits).

Baltimore Gas and Electric (BG&E), the largest utility in Maryland and another of Exelon Corporation's transmission and distribution businesses, recently proposed the establishment of two microgrids within its service territory to supply Edmondson Village in Baltimore City and Kings Contrivance Village Centre in Howard County [21]. If successfully developed, these microgrids will supply a mixture of residential customers, and vital community services at an estimated cost of approximately (USD) $3.5 million/MW. The Edmondson Village microgrid will service 3MW of load at an estimated cost of (USD) $9.2 million, with approximately 676,000 residents falling within a five-mile radius of the microgrid's service area. Similarly, the Kings Contrivance Village Centre microgrid will serve 2MW of load and cost an estimated (USD) $7.4 million, with approximately 217,000 residents falling within a five-mile radius of the microgrid's service area [22].

As pilot microgrids like those proposed by BG&E are constructed, and as the legislation, regulation, and financial mechanisms (e.g. tariffs) are reviewed and developed to enable microgrids, it is likely that Maryland will see a growing number of microgrid applications by utilities and private parties.

[5] Within the USA, while some states operate with deregulated or partially deregulated generation and retail sectors, transmission and distribution still remains a monopolised sector. The agreement between state or local public authorities and the transmission and distribution organisation that guarantees this monopolistic operation is termed a "franchise."

5.1.2.4 Massachusetts

In March 2014, the Commonwealth of Massachusetts established the Community Clean Energy Resiliency Initiative (CCERI) [23], a (USD) $40 million initiative targeted at improving the resiliency of municipal facilities and encouraging the deployment of clean energy technologies. Since being established this initiative has awarded (USD) $25.8 million in funding ((USD) $7.4 million in 2014 and (USD) $18.4 million in 2015) to 19 projects across the state. Similar to the Connecticut initiative (see Section 5.1.2.2), these projects have ranged from small multi-kW to larger multi-MW installations, with funding ranging from less than (USD) $100,000 to almost (USD) $4 million per project. Many of the larger projects incorporate existing generation, with the addition of renewable generation and energy storage, to provide resilient supply to a larger network area or group of facilities.

5.1.2.5 New Jersey

In October 2014, New Jersey Board of Public Utilities launched the New Jersey Energy Resilience Bank (ERB) [24], as part of the state's Community Development Block Grant for Disaster Recovery. The ERB has been allocated (USD) $200 million of funding (one of the largest allocations for this purpose) to support the development of distributed energy resources at critical facilities throughout the state, ultimately providing supply resiliency during major electricity outages. Although being open for applications since October 2014, the ERB is still awaiting the first successful proposal.

5.1.2.6 New York

In February 2015, the New York State Energy Research and Development Authority (NYSERDA) announced the Microgrid Prize, a (USD) $40 million competitive award to help build community-scale microgrids [25]. The program is targeted at developing at least 10 microgrids within the state of New York, and is structured in three stages:

1. **Feasibility study** – that provides up to (USD) $100,000 per project to conduct a feasibility study. Funding for Stage 1 studies, which was awarded in July 2015, was initially allocated for 25 projects, but this was later revised to support 83 projects. It is expected that these feasibility studies will be completed by February 2016.
2. **Design** – that provides up to (USD) $1 million per project for 10 projects to conduct detailed engineering design and business planning. Stage 2 applications will close in mid- to late-2016, with the successful applicants expected to deliver their designs by December 2017.
3. **Project build-out** – that provides up to (USD) $5 million per project for five projects to construction the microgrids and perform operational monitoring of the microgrid's performance. Stage 3 applications will close in April 2018, with the successful applicants expected to have utilised their allocated funds by September 2019.

5.1.3 Summary of State-level Policies and Initiatives

Table 4 provides an overview of the state-level microgrid incentive schemes and policies, highlighting the targeted microgrid scale, participating parties, number of projects awarded, and total funding available. From this table it is evident that current activity is largely targeted at smaller-scale microgrids. However, in many instances, these incentive schemes are targeted at developing experience, expertise, policies, and regulatory frameworks that will enable the larger-scale deployment of more complex microgrids.

Table 4: Summary of various state-level approaches to microgrid-related policies and incentive schemes

State	Launch Year	Targeted Microgrid Scale		Participating Parties		Projects Awarded	State Funding (USD, million)
California	2014	☑	Single customer	☑	Private	*8*[6]	$26.9
		☑	Partial-feeder	☑	Third-parties		
		☐	Full-feeder	☑	Utilities		
		☐	Substation	☐	Municipalities		
Connecticut	2012	☑	Single customer	☑	Private	11	$38
		☑	Partial-feeder	☑	Third-parties		
		☐	Full-feeder	☑	Utilities		
		☐	Substation	☑	Municipalities		
Maryland	2014	☐	Single customer	☐	Private	*Not available*	-
		☑	Partial-feeder	☑	Third-parties		
		☑	Full-feeder	☑	Utilities		
		☐	Substation	☐	Municipalities		
Massachusetts	2014	☐	Single customer	☑	Private	19	$40
		☑	Partial-feeder	☑	Third-parties		
		☐	Full-feeder	☐	Utilities		
		☐	Substation	☑	Municipalities		
New Jersey	2014	☑	Single customer	☐	Private	0	$200
		☑	Partial-feeder	☐	Third-parties		
		☑	Full-feeder	☐	Utilities		
		☐	Substation	☐	Municipalities		
New York	2015	☑	Single customer	☑	Private	*5*[7]	$40
		☑	Partial-feeder	☑	Third-parties		
		☐	Full-feeder	☑	Utilities		
		☐	Substation	☑	Municipalities		

5.1.4 Lessons Learned

Historically, the development of microgrids has occurred on a somewhat ad-hoc basis, targeted toward single customers or facilities (e.g. data centres and large commercial or industrial facilities). In these instances, the cost of microgrid development is offset by savings and increased productivity gained as a result of the reduced exposure to outages and downtime when compared with a "standard" utility connection. For the most part, larger scale, multi-customer, partial- or full-feeder, community microgrids have seen limited application. This is namely due to the significant cost associated with development and the limited availability of value streams that provide financial benefit to the developer or operator. However, severe weather events like those of Hurricane Katrina (2005) and Hurricane Sandy (2012), as well as PPD-21 (2013) have demonstrated the importance of developing a resilient electricity network, generating increased interest around microgrids.

In the short- to medium-term, it is unlikely that community microgrids will provide a profitable business opportunity for private or independent owners, without substantial subsidies or incentives (such as those documented in this report). As a result, for community or public interest microgrids, it is likely that utility ownership will prevail within this timeframe. In addition to having access to large existing distribution and communication networks, and expertise around system development and operation, utilities have the capability to make investments on behalf of, and for the benefit of the public. Moreover, utilities have existing mechanisms to recover the costs of microgrid investment (i.e.

[6] A total of 17 projects have been awarded under PON-14-301, however only eight directly relate to microgrids.
[7] It is important to note that, at present, 83 projects are undergoing feasibility analysis. It is expected that by the construction stage of this award only five projects will receive funding.

distribution use of systems charges). However, it is important that existing regulatory frameworks (that generally operate on a state-by-state basis) are revised to allow and ensure prudent investment in microgrids.

In the long-term, as the availability of distributed generation grows, and legislation and regulation around microgrid ownership and operation adapts, it is possible that independent or hybrid ownership models will prevail; however, even with the required legal and regulatory changes, these ownership models still present a complex operating model. In this instance, a single entity would be required to ensure the safe and stable operation of the wider grid, possibly foreshadowing the need for a distribution system operator role, similar to that of the regional transmission organizations (RTOs) (e.g. PJM Interconnection) or independent system operators (ISOs) that are responsible for managing the operation of the transmission grid.

Ultimately, if microgrids are to become a large-scale solution to addressing issues with system resiliency and security it is important that a federal-level microgrid roadmap is developed. This roadmap should guide the deployment of microgrids across the USA, addressing issues such as:

- Regulatory frameworks that enable microgrid development;
- Guidelines for the application of microgrids to different network and customer scenarios that outline where microgrids provide greatest value;
- Models for wide-scale deployment of utility, private, and independent community microgrids, and recovery mechanisms for each of these models;
- Standardised metrics for measuring microgrid success and improvements in performance; and
- The relationship between existing utilities and potential private or independent community microgrids.

Such a roadmap would help to ensure that microgrids are suitably and sustainably deployed in ways that provide greatest value to customers and wider society.

5.2 Distributed Generation Hosting Capacity

In Section 5.1 of my Fourth Quarterly Report [2], I presented the concept of DG hosting capacity, and outlined how I was working to apply this technique to ComEd's network. Building upon this work, in Section 5.2 of my Fifth Quarterly Report [3], I discussed the ongoing development of this algorithm and some of the challenges faced. In this quarterly report, I will conclude my work in this area.

5.2.1 Finalising Algorithm Analysis and Documentation

Over the past quarter, I have spent a large portion of my time working to finalize the system-wide hosting capacity analysis of ComEd's 4kV and 12kV distribution network. This works has entailed:

- Utilizing the algorithm, as detailed in past quarterly reports [2, 3], to estimate the hosting capacity of each of the 5,385 4kV and 12kV distribution feeders across ComEd's service territory and to provide a whole-of-system hosting capacity estimate. This report documented the entirety of my efforts in this area, including providing a detailed explanation of the algorithm, assumptions, limitations, and future work for the DG hosting capacity algorithm.
- Compiling a database that backed this system-wide analysis. Given the amount of data generated through detailed hosting capacity simulations of feeders (more than 800 successful feeder models) and the variety and complexity of reports compiled from this data (e.g. for use in my final report), it was not feasible to manage this data and reporting in an Excel workbook. As such, I developed a structured, relational database as a central repository for management of hosting capacity data and associated reporting.
- Developing detailed technical code documentation to accompany the hosting capacity code. This documentation provides a detailed breakdown of each of the classes and their inherent functionality, while also imparting some commentary on certain developmental decisions and direction pertinent to the code and its functionality. Although this document will not have a broad readership; it is intended as a "handover" and reference document for engineers who may work on the hosting capacity algorithm in future.
- Providing a handover workshop to two of my colleagues within the Smart Grid and Technology team that gave a detailed understanding of the distributed generation hosting capacity, the hosting capacity algorithm and accompanying code, and future work and limitations.

Given that the content of this work is specific to ComEd's distribution network and intellectual property, I am not at liberty to discuss these items in more detail beyond that which was included in past quarterly reports.

In the past quarter I have also worked with my colleagues to prepare a paper for submission to the CIGRÉ United States National Committee Paper Competition. The paper discusses our learning around the application of clustering techniques specifically for hosting capacity analysis, but also for generally characterizing distribution networks (as has been applied in a number of different publications). If accepted this paper will also be presented at the "Grid of the Future Symposium" in Philadelphia, Pennsylvania on the 30th October 2016.

5.2.2 Lessons Learned

Over the past nine months, I have learned a great deal about probabilistic modelling techniques (namely Monte Carlo simulations), the application of big data analysis techniques to real-world analysis, and the varied and diverse challenges of incorporating DERs on a traditionally unidirectional distribution network. Among these learnings, a number of challenges have highlighted the complexity of accurately quantifying the hosting capacity of a distribution feeder, and, more so, the system-wide hosting capacity.

Given the current state-of-the-art analysis, I believe that these figures provide a good relative measure of a distribution feeder's ability to accommodate DG. On an absolute level, there is still some room for improvement; however, as these techniques continue to mature they will provide a more accurate screen with which to expedite and fast-track DG interconnection requests when compared to the existing, heuristic screening techniques [26, 27].

Within Australia, it may be argued that these algorithms have limited value given the already high penetration of DG; however, I believe that these techniques provide and ongoing benefit to utilities as they continue to grapple with a large number of residential solar PV applications [28, 29]. In addition to providing high-confidence expedited screening of interconnection requests, these techniques can aid utilities in:

- Identifying the impact of existing DG on feeder and system hosting capacity. Such analysis would provide valuable input to the revision of existing incentive schemes, particularly in devising schemes that encourage a more technically and financially sustainable uptake of DG.
- Justifying prudent network investment required to accommodate these DG systems.
- Quantifying the marginal impact of additional DG systems. This would assist in the development of a more equitable recovery mechanism for the cost of network augmentations triggered by DG deployment (e.g. a scaled network interconnection fee based on the impact of a DG system on the overall feeder or system hosting capacity).
- Targeting optimal locations for DG deployment, where possible[8].

Moreover, as these techniques are developed and become more readily accessible (i.e. incorporated within standard network analysis applications), it is inevitable that additional applications for this data will be identified.

[8] It is important to note that distribution utilities are required to provide equal access for customers wanting to connect DG to the system.

5.3 Power Quality Strategy

Electrical systems, be that simple consumer electronics, or commercial- and industrial-scale electronics and electrical systems, are susceptible to damage or disruption due to poor power quality (PQ). These disruptions can inconvenience customers, degrade their experience (e.g. flicker visible in lighting), or, in the more costly eventuality, damage equipment and bring systems and processes to a halt, reducing productivity and increasing system downtime. In the past decade the impact of poor power quality has been estimated by a number of studies [30, 31] in the USA and [32] in Europe. In [30] it is estimated that USA's economy loses between (USD) $140 billion and $221 billion annually from outages (of any duration), with an additional (USD) $20 billion to $32 billion in losses resulting from other power quality events[9]. Figures from [31] show a lower estimate of (USD) $93 billion in annual losses resulting from outages, with the suggestion that the actual figure may range anywhere between (USD) $26 billion and $160 billion annually[10]. Ultimately, although the exact number is debatable, it is evident that major global economies suffer loss in the order of tens of billions of USD per year, as a result of PQ-related events.

Historically, identifying the occurrence of these issues has been difficult and relied, for the most part, on customers reporting the occurrence of issues like lighting flicker, brownouts, or intermittent service and equipment interruptions. In an attempt to more proactively identify and address these PQ events, ComEd is working to utilize data captured by customer smart meters installed as part of Illinois' Energy Infrastructure Modernization Act (see Section 4.4 of [2]), as well as a number of specialized power quality monitoring devices(e.g. SEL 735 PQ meters). As a part of this effort, I was tasked with drafting a discussion paper that outlined ComEd's existing capability to monitor PQ issues and propose a plan to systematically identify and address these issues across ComEd's distribution system. Given the sensitive and confidential nature of this work, I am not able to discuss it in detail; however, this section provides a high-level overview of the content of the discussion paper and the proposed process.

The first goal of the discussion paper and a vital step in developing a system-wide PQ strategy was to build a clear definition of what "PQ issues" entailed, possible causes, and related impacts. Generally speaking, a PQ event can be considered any deviation in supply from a perfect sinusoidal waveform, that has voltage amplitude and frequency matching the system nominal specification (e.g. 50Hz, 325V amplitude / 230V RMS supply for a standard Australian service). This broad definition encompasses a number of broadly different distortions and disturbances, each of which can have differing impacts on the system and customers. Table 5 provides a summary of these PQ issues and a description of their basic attributes, while Table 6 details the general electrical characteristics of these PQ events.

In general, PQ events can be classified as transient or steady state depending on the event duration. Transient events are those that occur over a relatively short timeframe (generally on the order of cycles[11] or fractions of a cycle). By their nature, these events are generally the most difficult to detect, requiring sensitive devices that are capable of monitoring voltage and current waveforms with sub-cycle sampling. Conversely, steady state events are longer duration, sustained events that may be easier to detect owing to their more persistent occurrence.

[9] These figures are provided in 2016 USD figures and are calculated from 2001 USD figures provided in [30], indexed based on the average annual inflation rates sourced from [34].
[10] These figures are provided in 2016 USD figures and are calculated from 2006 USD figures provided in [31], indexed based on the average annual inflation rates sourced from [34].
[11] The term "cycles" is used to refer to the period of the fundamental current and voltage waveform (16.7ms for 60Hz within the USA, and 20ms for 50Hz in Australia).

Table 5: Summary of power quality issues

	Issue	Description
Transient	**Voltage sag**	A short-duration reduction in root mean squared (RMS) voltage. Voltage sags are one of the biggest concerns for commercial and industrial customers as they can adversely affect manufacturing and electronic systems compromising quality or halting entire processes. A number of standards have been developed (e.g. IEC 61000-4, ITIC, IEEE P1668, SEMI F47) that set requirements for devices (predominantly electronics) to ride-through voltage sags depending on sag severity.
	Voltage swell	A short-duration increase in the RMS voltage.
	Current / voltage surge	An impulse change in the current or voltage waveform that occurs on the timescale on nanoseconds to microseconds.
	Momentary interruption OR Temporary interruption	A momentary interruption is defined as a loss of supply that is sustained for a few seconds or less. Although only transient, these outages can be sustained long enough to cause power down of electronic devices. A temporary interruption are those interruptions that are still short in duration (a few seconds to one minute), but that are longer than a momentary interruption. Similar to momentary interruptions, these outages are likely to cause most electronic systems to power down.
	Frequency deviations	The Australian power grid has a nominal operating frequency of 50Hz; however, owing to variations between generation and demand on the system this frequency deviates from the nominal 50Hz. This level of deviation can have local impacts (e.g. for devices that rely on this 50Hz waveform for timing) or more broad system impacts as an indication of wider system instabilities.
Steady state	**Harmonics**	Periodical deviations or distortions in the fundamental 50Hz sinusoidal voltage and current waveforms. These deviations can be described mathematically by the summation of higher frequency (i.e. higher than 60Hz) sinusoidal waves known as “harmonics”.
	Unbalance (voltage and current)	A difference in the RMS voltage or current magnitude or angle between each phase.
	Under-voltage	A sustained low RMS voltage, lower than the required minimum voltage service voltage.
	Over-voltage	A sustained high RMS voltage, higher than the required maximum voltage service voltage.
	Power factor	Power factor is determined by the phase difference between the voltage and current wave forms. This phase shift (termed “leading” or “lagging” depending on relative shift) results in the production of reactive power. Reactive power is unproductive, in that it cannot be used in completing work (by the scientific definition) but still requires current and utilizes network capacity to be transferred.

Table 6: Typical timescale and magnitude for power quality issues [33]

Issue	Timescale	Magnitude
Current / voltage surge	Nanoseconds - milliseconds	>>1pu
Momentary interruption	8.33 milliseconds (0.5 cycle) - 3 seconds	0pu
Voltage sag	8.33 milliseconds (0.5 cycle) - 1 minute	0.1-0.9pu
Voltage swell	8.33 milliseconds (0.5 cycle) - 1 minute	1.1-1.8pu
Temporary interruption	3 seconds - 1 minute	0pu
Frequency deviations	Transient / steady state	5%
Under-voltage	> 1 minute	0.8-0.95pu
Over-voltage	> 1 minute	1.05-1.2pu
Unbalance (voltage and current)	> 1 minute	Voltage - >0.03pu (of RMS value)
Harmonics	Steady state	2%-5% (third harmonic)
Power factor	Steady state	<0.9 leading or lagging

For each of these PQ events the discussion paper detailed:

- Possible causes for each PQ event;
- Impacted parties, namely, residential, commercial or industrial customers, or distribution or transmission system owners;
- Impacted equipment, for example motors, programmable logic controllers, relays; and
- Impacted processes or systems (e.g. manufacturing, data centres, amusement parks) were identified.

This breakdown was vital in providing an understanding of how the various PQ events my impact customers broadly, while identifying specific PQ events that are particularly pertinent to customers within ComEd's service territory.

Building upon this basic, qualitative assessment, I investigated the application of a quantitative risk assessment that would enable a dollar-value estimation of the cost of power quality issues for customers, ComEd as a utility, and society. This review took into account Exelon Corporation's, "*Enterprise Risk Management Policy and Framework,*" as well as other industry-developed documentation like CIGRÉ's, "*Economic Framework for Power Quality*" [34]. Such an assessment would allow ComEd to understand when the cost of PQ events (or conversely, the benefit of mitigating these events) outweighed the cost of remediating work, in turn allowing for the development thresholds for PQ severity that could be utilized in developing a remediation plan.

The final component of the discussion paper outlined the PQ monitoring capabilities of ComEd's existing metering and relay infrastructure, which consisted predominantly of:

- General Electric (GE) I210+C single-phase meters, that have been deployed for residential customers;
- GE KV2C three phase meters, that have been deployed for commercial and industrial customers; and
- Schweitzer Engineering Laboratories (SEL) 753 power quality and revenue meters, that are being deployed in specific locations and as a part of ComEd's smart substations.

It is envisaged that this information will be utilized as a part of future revisions to the discussion paper and the development of ComEd's, "*System Power Quality Strategy*".

Ultimately the proposed plan envisages the development of geographical reports that detail the prevalence of different PQ events, alongside a map of sensitive or at-risk customers. The combination of these analytics, in addition to the quantitative risk assessment and "PQ thresholds," will allow ComEd to identify and prioritize areas of their system that should be targeted for remedial augmentations.

5.3.1 Lessons Learned

In developing the PQ strategy discussion paper I extended my understanding of PQ issues and the impacts of these events on customers, the distribution and transmission system, and wider society. From my literature review and research into economic assessment techniques, it is evident that PQ events can substantially impact the productivity and quality of many commercial and industrial industries, while also having broader impacts on customer experience. To date, it has been difficult for utilities to identify or measure these issues without the deployment of specialised, and often costly PQ monitoring equipment. However, the deployment of smart meters at customer premises will provide partial visibility of many of these events, particularly voltage sags and swells which tend to be of greatest concern for customers.

Within Australia a number of states have begun rolling out (e.g. South Australia, New South Wales, and Western Australia) or have widely deployed smart meter technologies (e.g. Victoria). As a part of

these (and future) deployments, distribution network operators will have increased visibility of PQ events. With this increased visibility comes a need for:

- Definitive definitions outlining the conditions around each PQ issue (e.g. duration and magnitude);
- The inclusion of PQ events in performance or service standards; and
- The deployment of metrics with which to measure PQ performance at a utility or system level.

Such developments will aid in providing an industry-standard approach to measuring and managing power quality issues. Moreover, as visibility of PQ events increases it may not be economically viable for utilities to mitigate all PQ issues across their system. To this end, it is important that a risk-based approach is taken to consider the frequency (or likelihood) and impact (or consequence) of these events, addressing PQ issues in a prioritised manner.

6 Closing

As this is my sixth and final quarterly report, I have now concluded my 18-month tenure on the E.S. Cornwall Memorial Scholarship. During this time, I have been able to explore the utility environment in the UK and USA, working on a number of interesting and challenging projects that have spanned asset management, emerging technologies, and renewable generation. Outside of the core work of my placements I have had the opportunity to attend a number of site visits to manufacturers, research facilities, and other utilities. In my personal time, I have been able to travel and experience the rich culture and history that Europe and the USA have to offer. For these opportunities and for having received the E.S. Cornwall Memorial Scholarship I am humbled and forever grateful.

There are a number of people that I would like to acknowledge for their contributions to my time abroad:

- To the many people that I have had the pleasure to work and socialise with along the way, thank you. It is the people that make an experience like this so valuable and enjoyable. My time abroad has been filled with many memories, but it is those memories shared with friends and colleagues that I will remember most fondly.
- To Ergon Energy, my Australian employer, thank you for allowing me this time to work, research, and explore the international utility environment. I am excited to work for an organization that has a history of supporting and continues to support engineers developing themselves through opportunities like this.
- To the E.S. Cornwall Memorial Scholarship and the Scholarship Board, thank you for continuing to provide this opportunity to young engineers like myself. The work that you enable on this scholarship drives the careers of young engineers and plays a vital role in developing knowledge and expertise within the Australian Electricity Industry.
- And lastly, but most importantly, to my family, who have taken on the somewhat undesirable role of “Report Vetters”. Thank you for your love, support, and words of encouragement that have carried me through my time abroad.

To young, Queensland-graduate engineers who are considering applying for the E.S. Cornwall Memorial Scholarship - do! While I can assure you that it’s not always easy, it’s worth it. The experiences and challenges you will face during your time on the scholarship will grow you as a person, develop you as an engineer, and leave you with a collection of life-long memories. I’m more than happy to share my experience and advice with anyone who is considering applying for the scholarship and can be contacted by email (matthew.zillmann@gmail.com).

As I return home, I look forward to applying the skills and knowledge I have garnered over the past 18 months to my role in Ergon Energy, where I will be working as a Substation Maintenance Standards Engineer based in Brisbane, Queensland. I am particularly looking forward to the challenge of further developing Ergon Energy’s condition monitoring package and improving integration with the asset condition-based risk management (CBRM) application in calculating asset health indices.

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