E. S. Cornwall Memorial Scholarship

Second Quarterly Report

UK Power Networks

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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 relate to any person or organisation associated with the author. Any reproduction or referencing of this report should reflect this.

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1 Glossary, Abbreviations & Definitions

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

Terminology / Acronym / Abbreviation	Definition
"Ofgem"	UK Office of Gas and Electricity Markets
AER	Australian Energy Regulator
AIP	Annual Iteration Process
BMCS	Broad Measure of Customer Satisfaction
CAPEX	Capital Expenditure
CI	Customer Interruption
CML	Customer Minute Lost
ComEd	Commonwealth Edison, Chicago, USA
DNO	Distribution Network Operator *Refers to the network owners (e.g. UKPN) as opposed to license areas*
DPCR	Distribution Price Control Review
ED1 (as used in RIIO-ED1)	Electricity Distribution regulatory period 1 (2015 -2023)
GSoP	Guaranteed Standards of Performance
IET	Institute of Engineering and Technology
IIS	Interruption Incentive Scheme
IQI	Information Quality Incentive
IRM	Innovation Roll-out Mechanism
LRE	Load Related Expenditure
NIA	Network Innovation Allowance
NIC	Network Innovation Competition
OPEX	Operational Expenditure
PCFM	Price Control Financial Model
RAV	Regulatory Asset Value
RIG	Regulatory Instructions and Guidance
RIIO	Revenue equals Incentives, Innovation and Outputs
RORE	Return on Regulatory Equity
SF_6	Sulphur Hexafluoride
TIM	TOTEX Incentive Mechanism
TOTEX	Total Expenditure
TWPL	The Woodhouse Partnership Limited
UKPN	UK Power Networks
WACC	Weighted Average Cost of Capital
WPD	Western Power Distribution

2 Executive Summary

In the latest round of draft regulatory determinations, involving DNOs operating in New South Wales and the Australian Capital Territory (for the 2014-2019 regulatory period), the Australian Energy Regulator has issued exacting cuts to the CAPEX and OPEX of affected DNOs. Reductions of circa 30-40% demonstrate now and into the future that the Australian Energy Regulator will take drastic action where it feels DNOs are overinvesting in their assets or operating inefficiently. This may include looking to the success of regulatory models internationally and adopting measures that will reward the efficient and sustainable development of networks.

This report provides an overview of my work with UK Power Networks' Regulation team, including my subsequent research. Through this work I have developed a good understanding of the framework and challenges of the RIIO model utilised by the UK regulator, the Office of Gas and Electricity Markets ("Ofgem"). Although RIIO was developed for a longer, eight year regulatory (or price control) period, the various incentives, mechanisms, performance monitoring, and output targets offer a flexible and responsive framework. If the Australian Energy Regulator is to further challenge utilities it may look to adopt similar mechanisms, including:

- extending existing incentive schemes;
- increasing competition between DNOs;
- utilising a defined set of output and performance measures to track the performance of DNOs, while providing flexibility for innovation and efficiency in achieving these targets; and
- establishing annual review in a similar mould to that of the Annual Iteration Process, which reviews utility performance throughout the regulatory period and adjusts allowed expenditure and revenue accordingly.

During the past quarter I have also continued my involvement with: Engineering Standards on UK Power Networks transition to ISO55000, where I worked heavily on the "Asset Management Manual;" and Asset Strategy and Performance on the Asset Risk and Prioritisation tool documenting the distribution transformer model and verifying functionality of the fluid filled cable model.

In the coming months I will continue to work on the ISO55000 transition while undertaking work on the Element Energy Load Growth model and acquiring exposure to the Imperial College of London Load Related Expenditure model, whilst also working on a project on online partial discharge monitoring of cables with the Future Networks team.

3 Introduction

This report builds on my previous quarterly report undertaken on the E. S. Cornwall Memorial Scholarship. For more information on past and future 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][1].

During the same period advances in distributed generation 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 on the network to improve network performance as an alternative or method 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 second of six quarterly reports that will be compiled throughout my placements on the scholarship. It covers the second three (of a total nine) months that I will spend at UKPN based in Crawley, Sussex, England.

[1] *For indicative purposes only*, over the same period the UK saw a circa 15% increase in the price of domestic electricity (calculated form [16]) with 16% of this price consisting of distribution and 4% of transmission charges (excluding taxes) [17, 9].

In the second three months of my placement with UKPN I have continued working in the Engineering Standards and Assurance team, as well as continuing my involvement with the Asset Risk and Prioritisation and Distribution Network Visibility tools. I have also taken the opportunity to complete a short placement with the Strategy and Regulation group, who are responsible for interfacing with Ofgem and developing the regulatory submission (in collaboration with other directorates within the business). During this placement I developed an interest in understanding the RIIO model and its challenges. As such, I continued my research into RIIO beyond this placement with assistance and input from members of the Regulation team.

4 Background

For an overview of UKPN and Ofgem, see Section 4 of my first quarterly report [2].

5 Placement Experience

The following section is an overview of work that I have completed, including lessons learned from my experience. Where possible, I have drawn comparisons as to how my experience may be of value to the Australian electricity supply industry.

5.1 Regulation and RIIO-ED1

As discussed in my first quarterly report and in reports by past E. S. Cornwall Memorial Scholars (namely Robin O'Connor [3]), on the 1st April 2015 Distribution Price Control Review 5 (DPCR5) will conclude, heralding the start of RIIO for electricity distribution (RIIO-ED1). The RIIO model itself is not a new principal. Initially proposed following the "RPI-X@20" review [4], which concluded in late 2010, RIIO has already been applied to the transmission and gas distribution networks starting in April 2013 (RIIO-T1 and RIIO-GD1 respectively). While the transition to RIIO will see significant changes to aspects of the regulatory framework, there are many components of DPCR that have been reviewed or revised and continue to be utilised in RIIO. At the time of publication of this report, Ofgem was in final consultation with network owners over their acceptance of the final determination and license conditions for the April 2015 to March 2023 price control period.

To understand the impact of this regulatory model in incentivising prudent and sustainable expenditure in asset management and the organisation as a whole, I sought a brief but valuable placement with the Regulation team of the Strategy and Regulation directorate. Timing of this placement was opportune as it allowed for once-in-a-regulatory-period exposure, particularly being the first of the RIIO-ED price control periods. During this placement I:

1. Gained an understanding of Ofgem's final determination and assisted in communicating the outcome to the business. In particular, these communications highlighted differences between: the proposed plans at fast track, slow track, and final determination, how these variations will impact the business, and how UKPN (and its constituent license areas) faired against other DNOs.
2. Analysed historical (DPCR5) and planned (RIIO-ED1) cost, volume, and total expenditure (TOTEX) data, benchmarking UKPN's performance against other DNOs and their license areas. This analysis assisted in understanding areas of expenditure that UKPN was performing efficiently, or conversely where improvement was required (in comparison to other DNOs). Findings from this analysis were also used in communication for senior managers within UKPN.
3. More generally, drew on the regulatory and business experience of members of the Regulation team to learn about RIIO, Ofgem, and how UKPN is affected by RIIO-ED1.

Through my experience on this placement I was able to greatly improve my understanding of the UK regulatory environment, particularly in understanding challenges that DNOs are facing as a result of continuing pressure to improve performance and efficiency. As a member of this highly esteemed team I was also able to have valuable and frank discussions with Basil Scarsella (Chief Executive, UK Power Networks), Keith Hutton (Head of Regulation, UK Power Networks), James Hope (Head of Business Performance Management, formerly of Ofgem) who was heavily involved in the development and analysis related to DPCR and RIIO-ED, and Jo Sinclair (RIIO-ED1 Programme Manager, UK Power Networks).

5.1.1 Overview of Key Changes

The concept of RIIO initially put forward in the RPI-X@20 decision paper was for a regulatory model that would, "*…encourage network companies to play a full role in the delivery of a sustainable energy sector; and deliver long-term value for money network services for existing and future consumers.*" [4] Figure 1 provides a summary of how Ofgem sought to achieve this goal. In the five years since the RPI-X@20 report was published, Ofgem has built on these elements through consultation with distribution, transmission, and gas network operators to develop the specifics of RIIO and how it is applied.

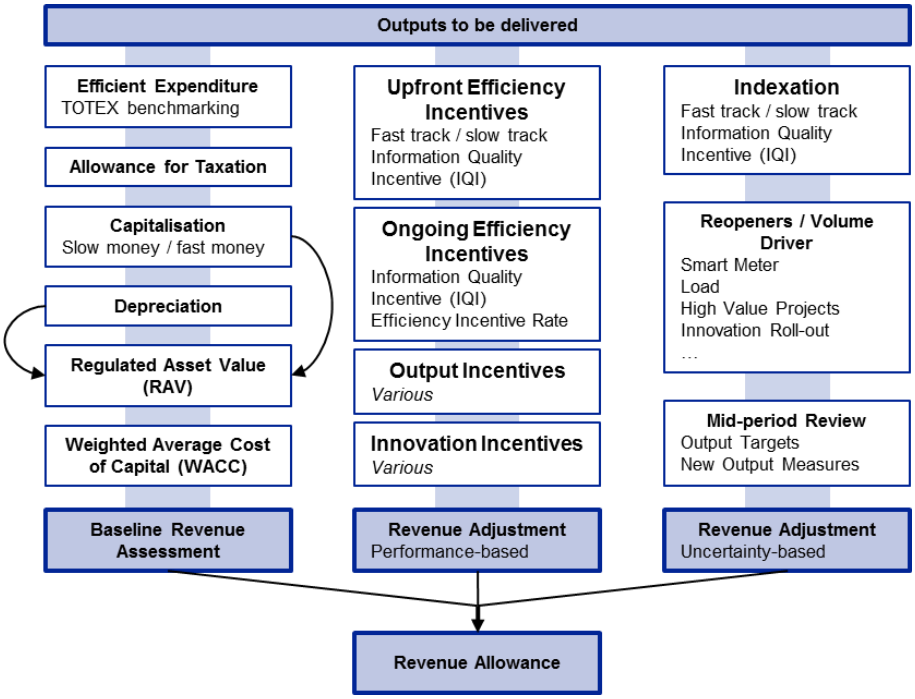

Figure 1: RIIO elements of sustainable regulation (adapted from [5])

The following sub-sections provide a high level overview of many of these elements, discussing key changes between DPCR and RIIO, and highlighting points of interest. It is not intended to provide readers with a complete understanding of the RIIO model. Where possible references are provided to more detailed explanation and documentation; in addition to these references, Ofgem's RIIO publication library [6] is an invaluable source of information.

Fast track and slow track determination

The establishment of a fast track assessment with the introduction of RIIO was a significant change to the regulatory submission process. The fast track process was established to encourage the submission of high-quality cost efficient business plans at first submission. If the business plan of a DNO (and its license area(s)) met Ofgem's criteria, Ofgem could choose to provide an early determination, prior to the beginning of the traditional price control period while also rewarding the DNO with a number of financial benefits. The incentives offered by Ofgem were:

- 2.5% increase applied to the DNO's proposed TOTEX; and
- 70% efficiency incentive rate (or sharing factor) (discussed later in this section).

For the RIIO-ED1 price control period only one DNO was successful in securing a fast track determination – Western Power Distribution (WPD) and its four license areas: South West, South Wales, East Midlands, and West Midlands. As an unintentional benefit of receiving the early determination WPD:

- secured a higher cost of equity (6.4% compared to 6.0% for slow track)[2];
- avoided additional real price effects (RPE) and smart grid cuts; and
- avoided the Information Quality Incentive (IQI) assessment process (discussed later in this section).

This was in addition to the obvious reputational benefit and increased certainty of receiving an early determination. Overall, if a DNO was able to meet the strict fast track requirements it stood to receive substantial tangible and non-tangible benefits.

[2] Ofgem reviewed this figure to ensure alignment with a ruling by the Competition Commission on the cost of equity for Northern Ireland Electric in November 2013.

It is worth noting that, as a result of their early determination, WPD were in some respects financially disadvantaged in comparison to other DNOs. During the longer, slow track negotiation process, DNOs were able to secure minor changes to the RIIO financial model. In particular WPD:

- did not receive the "trombone" rolling average[3] on their cost of debit, instead receiving a standard 10 year rolling average; and
- on average, over the price control period, received a marginally lower WACC.

Eight-year price control period and uncertainty mechanisms

One of the fundamental changes (impacting whole-of-business) introduced with the RIIO model was the change from a five to eight year regulatory period. The move to longer price control period is intended to encourage utilities to develop longer-term plans, while also providing a greater level of continuity, certainty, and stability. The obvious risk with longer duration price control periods is the possibility for change (e.g. economical, consumer, technology, legislative) beyond that predicted by DNOs, Ofgem, and stakeholders.

The diverse and ever-changing nature of society means that best estimates for load growth, usage trends, and economic development (to name a few) could change substantially with in the space of eight years. In an attempt to mitigate this risk Ofgem has allowed flexibility within the RIIO model through a number of uncertainty mechanisms. This is coupled with the requirement for annual reporting on expenditure and outputs, which drive revisions in TOTEX and annual revenue allowances through the Annual Iteration Process (discussed later in this section).

The uncertainty mechanisms that Ofgem has developed provide scope for:

- Reopeners and volume drivers relating to a number of different investment drivers or expenditure elements. These mechanisms provide Ofgem with a means to re-evaluate the TOTEX allowance of licences based on DNOs reaching a defined level of over- or under-expenditure (e.g. ±20% of allowance) in the case of a reopener, or seeing increased volumes above forecast in the case of volume drivers. To provide some certainty to DNOs, Ofgem has established defined timeframes for when reopeners and volume drivers will be assessed throughout the regulatory period.
- A mid-period review, which will reassess the validity of existing output targets and the need for any additional output measures. To avoid the possibility of the mid-period review becoming a significant review of the determination, effectively splitting the price control period, Ofgem has limited the scope of this mid-period review to outputs.

Output tracking and revenue adjustment

As one of the three core components of the RIIO model, the setting and continual monitoring of output targets enables Ofgem to track the DNOs' performance in delivering their plan throughout the price control period. This approach incentivises DNOs to optimise their costs (i.e. the cost to deliver components of their plan) and volumes (i.e. the amount of work undertaken to achieve their outputs) throughout the regulatory period. Where DNOs can deliver their outputs with reduced costs and volumes they stand to be rewarded. Conversely where DNOs are not able to reasonably justify under-delivery on outputs or over-expenditure they will be penalised. (See later sub-section on output, efficiency, and innovation incentives).

To ensure that DNOs are tracking against their outputs throughout the regulatory period Ofgem has established the requirement for an annual review of DNOs performance. This annual review requires that DNOs provide a suite of reports known as Regulatory Instructions and Guidance (RIG) reports[4]. These reports drive Ofgem's assessment of DNO performance and enable the adjustment of DNO's

[3] The term "trombone" rolling average is used by Ofgem to refer to an incremental duration rolling average, in this instance starting at 10 years and increasing annually reaching a maximum of 20 years.

[4] The use of standardized RIG reports is not new to RIIO-ED1; however, the format and content of the RIG reports is being reviewed and updated prior to the start of RIIO-ED1

TOTEX and revenue through the Annual Iteration Process (discussed later in this section). These reports are also made publicly available on Ofgem's website, providing an additional reputational incentive for DNOs to perform well.

Annual Iteration Process

The Annual Iteration Process (AIP) is one of the core financial uncertainty mechanisms introduced by Ofgem to provide flexibility during the eight-year price control period. It also places increased emphasis on DNOs to ensure they perform against their output targets (i.e. expenditure and delivery of outputs) throughout the price control.

Fundamentally the AIP involves re-evaluation the RIIO-ED1 Price Control Financial Model (PCFM), the model used to calculate the opening allowable annual base revenue for each license area (and subsequently each DNO). With each iteration a number of variables may be updated within the PCFM to align with latest data on performance, expenditure, economic conditions, and incentives. Where variables are linked to economic conditions or legacy issues, DNOs will have little or no means of impacting the PCFM; for example: taxation, pensions, cost of debit, and (to a lesser extent) the close out of schemes and mechanisms from past price control periods. However, a number of the variables (particularly those included in the TOTEX Incentive Mechanism) compare actual and allowed expenditure, making adjustments to TOTEX to account for under or overspending and the resultant penalty or reward on allowed base revenue. This process is summarised in Figure 2.

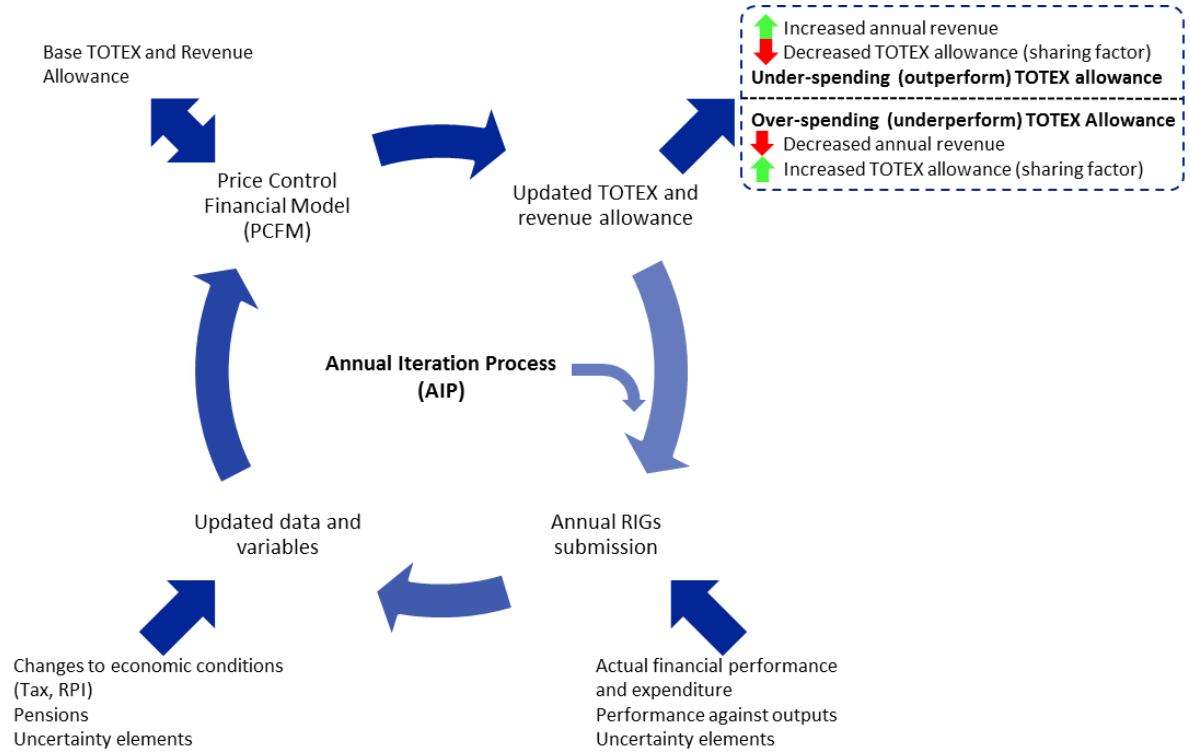

Figure 2: Summary of Annual Iteration Process (AIP)

To ensure awareness and transparency in this process, Ofgem has made the PCFM available to DNOs (and gas and transmission network operators) through their website. This model is updated annually following the latest revision of the AIP.

TOTEX cost assessment and benchmarking

Rather than utilising a CAPEX and OPEX split as the basis for cost estimation and benchmarking (as in DPCR5), Ofgem has utilised TOTEX (where TOTEX = CAPEX plus OPEX). In doing so, Ofgem aimed to:

- utilise a method of benchmarking that focused on overall business efficiency;
- avoid possible manipulation of CAPEX / OPEX cost categorisation; and
- better consider the different CAPEX / OPEX trade-offs that DNOs face.

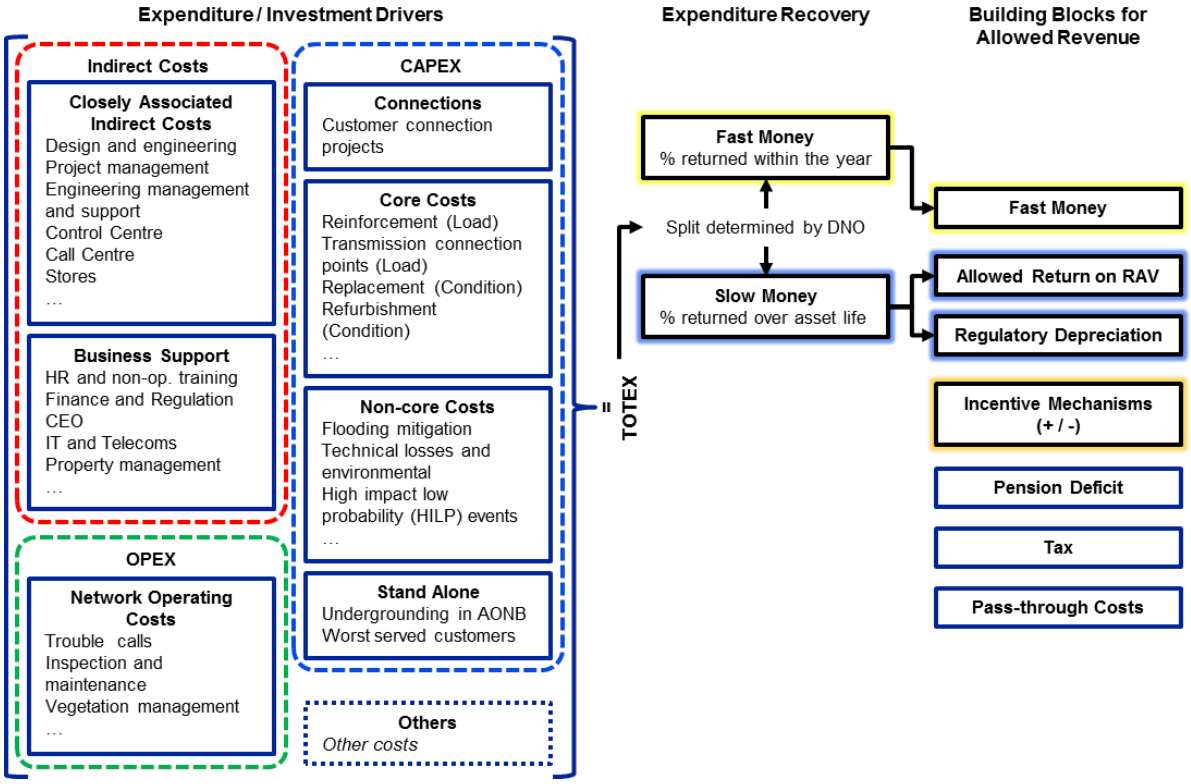

Figure 3: Overview of Ofgem's calculation of allowable revenue (adapted from [7])

Figure 3 shows a summary of the expenditure and investment drivers that Ofgem considers in the development of its cost assessment[5] (as documented in the RIGs reporting requirements). These cost drivers are used in Ofgem's benchmarking calculations, which estimate the efficient cost for DNOs using three models:

- the top-down TOTEX model, which provides a high-level cost assessment;
- the bottom-up TOTEX model, which uses a more detailed, but still high level cost breakdown; and
- the disaggregated activity-level model, which uses a highly detailed cost breakdown that is aggregated to calculate TOTEX.

The final calculation of Ofgem's view of efficient costs is a combination of these three calculations being weighted 25% for the top-down and bottom-up TOTEX models, and 50% for the disaggregated model. This is then "interpolated" against the DNOs cost assessment, with the final allowed TOTEX consisting of 75% from Ofgem's view of efficient costs and 25% from DNO's proposed costs.

Figure 3 also shows the two means of expenditure recovery, termed fast and slow money (discussed later in this section) and how the allocation of fast and slow money feeds into the calculation of allowed revenue.

[5] For a full list of investment drivers and populated example see Pages 13 and 14 of [19].

Fast and slow money

With the move away from using CAPEX and OPEX-based cost assessment and benchmarking, Ofgem utilised the concept of "fast money" and "slow money" to determine how costs are recovered by DNOs. Fast money is that which is paid within a financial year, generally required to cover its running (or OPEX) costs; while slow money is added to the DNO's regulatory asset value (RAV) and paid out over the defined asset life[6].

Considering these definitions, it is evident that fast and slow money is not a new concept and that the expected proportions of CAPEX and OPEX would largely determine the split of fast and slow money. The interesting and inherently new concept is that Ofgem allows DNOs to define their fast / slow money split (as highlighted in Figure 3). Historically, Ofgem calculated this based on the DNO's cost submission. For example, the proportion of fast money was historically calculated as the sum of business support costs, non-operational CAPEX, and 15% of all other expenditure, with the remainder being allocated to slow money [8].

5.1.2 Outputs and Incentives

The output incentives mechanisms utilised in RIIO-ED1 are not vastly different from those used in DPCR5. In some instances incentives have been reviewed and rationalised, others have been halted and new incentives put in place. With the strong output-driven focus of RIIO-ED1, each of these incentives have been linked to one of six core output areas. These incentive mechanisms are outlined in Table 2, which provides an overview of the various outputs and related Ofgem incentives (or requirements). More detail on these incentives is available on Ofgem's website[7] or as referenced.

Table 2: RIIO-ED1 primary and secondary output incentives

	Incentive / Requirement	Max Exposure (+ / -)
Safety	Health and Safety Executive[8] regulation and legislation	*None*
	Ofgem requires that all DNOs are compliant with the relevant legislative requirements of the Health and Safety Executive. There is no financial incentive associated with this output as Ofgem felt that doing so would act to duplicate functionality of the Health and Safety Executive, while also having possible detrimental impact to safety [9]. For more information on Ofgem's requirements for safety see Section 5 of [9].	
Environmental Impact	• Electrical Losses • Electrical Theft • Business Carbon Footprint • Sulphur Hexafluoride (SF_6) • Fluid-Filled Cables • Noise Reduction • Undergrounding in Areas of Natural Beauty and National Parks	*See incentives*

	Ofgem has established a number of incentives and requirements against the environmental impact output. These include:
	• The **Electrical Losses incentive**, which has been used in the past[9], is aimed at encouraging DNOs to reduce network losses (estimated between 5-8% of total electrical energy [10]). The losses incentive consists of four components:
	  ○ License requirements to design and operate their network in a way that would minimise losses as much as reasonably practicable (i.e. using cost benefit analysis).
	  ○ The inclusion of strategies for fulfilling the aforementioned license requirement in DNO's business	

[6] Previously the expected economic asset life had been set at 20 years. In RIIO-ED1 this asset life will transition from 20 to 45 years on a sliding scale to be applied to all new assets.
[7] www.ofgem.gov.uk
[8] The Health and Safety Executive is a non-departmental public body responsible for regulation of workplace health and safety in the UK (excluding Northern Ireland).
[9] The Electrical Losses incentive was used in DPCR4, but issues with reporting and data quality resulted in disproportionate rewards and penalties for DNOs. As a result, this incentive was deactivated in DPCR5 pending review and planned reintroduction in RIIO-ED1 [10, 18].

<table>
<tr><th></th><th>Incentive / Requirement</th><th>Max Exposure (+ / -)</th></tr>
<tr><td></td><td>plans. Ofgem requires that business plans identify loss reduction work and expense with an accompanying cost and benefit analysis. Furthermore there is the requirement that business review this work throughout the price control period to ensure that their approach to loss reduction remains relevant and in alignment with industry best practice.
○ Annual reporting on completion of loss reduction work comparing performance against proposed cost and benefit analysis. This is a significant change from the DPCR4 model that required DNOs to report on loss volumes and reduction achieved.
○ Losses Discretionary Reward, which consists of a maximum £32m to be shared across all DNOs to encourage loss reduction work in excess of that identified in a DNOs business plan(s). The money available for this incentive will be awarded using a scorecard based on proposals received from DNOs. (The criterion for this assessment process is yet to be finalised).
• Electricity Theft requirements, whereby Ofgem has introduced more stringent license conditions clearly defining the responsibility of DNOs. These license conditions require DNOs to be more active in monitoring, detecting, and preventing electricity theft (above and beyond the role of suppliers)[10].
• The Business Carbon Footprint, SF_6, Fluid-Filled Cable, and Noise Reduction incentives, which all require DNOs to report on their current state and performance. These reports are published on Ofgem's website and are devised as a reputational incentive for DNOs. The level of reputational incentive varies from: direct competition in the case of the Business Carbon Footprint incentive that consists of a league table of DNO performance including actions undertaken to reduce their footprint; to public awareness in the case of fluid-filled cables and noise reduction.
• The Undergrounding incentive, which was utilised in DPCR4 and DPCR5, provides funding for DNOs to underground overhead lines in areas of outstanding natural beauty or national parks to minimise visual and environmental impacts. Funding is provided by license area and is calculated on the basis of willingness to pay, impacted km of overhead line, and number of customers. The total funding allocated in RIIO-ED1 across all license areas is £103.6m.

For more information on Ofgem's environmental impact incentives and requirements see Section 5 of [9].</td><td></td></tr>
<tr><td rowspan="2">Customer Satisfaction</td><td>Broad Measure of Customer Satisfaction (BMCS):
• Customer Satisfaction Survey
• Complaints
• Stakeholder Engagement</td><td>±1.5% (base annual revenue)</td></tr>
<tr><td colspan="2">The BMCS, which was utilised during DPCR5, incentivises DNOs to provide good customer experience beyond that of the customer interruption (CI) and customer minute lost (CML) reliability incentives. The BMCS consists of three underlying incentive mechanisms:
• The Customer Satisfaction Survey, which polls a random sample of customers who have had dealings with DNOs in connections, interruptions, and general enquiries asking them to rank their experience. Depending on the resultant ranking DNOs can be rewarded or penalised to a maximum of ±1% of base annual revenue.
• The Complaints metric, which aims to ensure customer complaints are resolved in a timely manner. DNOs are measured against the percentage of total complaints that are: outstanding after one day, outstanding after 31 days, repeat complaints, and where an Energy Ombudsman makes a finding against the DNO (with each having different weightings). Unlike the Customer Satisfaction Survey, there is no reward for reaching or outperforming targets; rather this incentive penalises DNOs to a maximum of -0.5% of base annual revenue for underperformance.
• The Stakeholder Engagement incentive, which encourages DNOs to actively involve stakeholders in the long-term planning of their business. Metrics around this incentive appear somewhat qualitative, with the possibility of a +0.5% reward of base annual revenue at Ofgem's discretion.

For more information on Ofgem's customer satisfaction incentives see Section 6 of [9].</td></tr>
</table>

[10] Ofgem has established additional requirements and incentives impacting electricity suppliers (retailers); however, given that they do not directly impact DNOs I have not covered them in this report.

<table>
<tr><th></th><th>Incentive / Requirement</th><th>Max Exposure (+ / -)</th></tr>
<tr><td rowspan="2">Social Obligations</td><td>Vulnerable Customers</td><td>None</td></tr>
<tr><td colspan="2">Ofgem has not identified a specific output incentive relating to social obligation[11]; however, Ofgem has provided strong guidance that DNOs should be active in addressing social issues like vulnerable customers and fuel poverty. In particular, Ofgem has indicated that there will be heavy linkage between performance in this area and that of the BMCS incentive (namely stakeholder engagement). DNOs are required to document (as a part of their business plan) how they propose to identify and assist vulnerable customers.

For more information on Ofgem’s social obligation requirement see Section 7 of [9].</td></tr>
<tr><td rowspan="2">Connections</td><td>• Customer Satisfaction Survey (included in BMCS for connections)
• Time to Connect (for minor connections)
• Incentive on Connections Engagement (for major connections)
• Guaranteed Standards of Performance (GSoP)</td><td>+0.4% / -0.9%[12] (base annual revenue)</td></tr>
<tr><td colspan="2">Ofgem found that the incentive system used during DPCR5 did not sufficiently encourage DNOs to provide a timely connection service. As a result they have reviewed the connections incentives providing three mechanisms, two for minor (low voltage) and one for major (high voltage) connections. These incentives are:
• A component of the Customer Satisfaction Survey (minor connections), as incorporated in the BMCS. The connections component of the BMCS was increased from +0.32% / -0.2% base annual revenue exposure in DPCR5 to ±0.5% in RIIO-ED1 to encourage DNOs to provide a prompt, high-quality connection service for customers.
• Time to Connect (for minor connections), which measures the time from initial contact to issuing of quotation and connection of customer. Ofgem has issued performance targets covering both of these milestones (i.e. time to quote and connection) and where DNOs are able to outperform these targets they stand to receive a reward of +0.4% of base annual revenue. These targets will be reviewed (and likely reduced) half way through RIIO-ED1. For more information on the targets set by Ofgem see [11].
• Incentive on Connections Engagement (for major connections), which is targeted at improving the level of service for major connection customers. DNOs are required to document (in their business plans) their proposed plans for engagement and delivery of major connections. This is to be accompanied by routine evidence-based reporting to Ofgem demonstrating a DNO’s performance on major connections across different market sectors (e.g. metered, unmetered, and distributed generation). These submissions will be reviewed by Ofgem and assessed against a set of minimum performance standards. Where a DNO is found to have not met these minimum performance standards they may be penalised to a maximum of -0.9% of base annual revenue.
• Guaranteed Standards of Performance (GSoP), was established as a license condition in DPCR5 to encourage prompt, high-quality service for non-contestable customer connections. It stipulates maximum allowable timeframes for DNOs to provide quotation, design, and energisation to a customer. Failure to meet these timeframes or where a deliverable is found to be inadequate results in set penalties for the DNO (payable to the customer) dependant on the type of connection.

For more information on Ofgem’s connections incentives see Section 8 and Appendix 3 (GSoP payments) of [9].</td></tr>
</table>

[11] This does not preclude an incentive from being established in the future.
[12] This figure does not include the ±0.5% incentive for customer satisfaction (minor connections) (as it is already incorporated in the BMCS) or penalties accrued through the GSoP license requirement (as this is applied on a case-by-case basis).

	Incentive / Requirement	Max Exposure (+ / -)
Reliability and Availability	• Interruption Incentive Scheme (IIS) • Guaranteed Standard of Supply • Worst-Served Customer • Health, Criticality, Risk and Load Indexes • Resilience	*See incentives*
	Ofgem has established a number of network-focused incentives to ensure that DNOs operate and maintain networks in a sustainable way, ensuring a good service for customers, capacity (availability), and reliability in the short- and long-term. These incentives are: • The **Interruption Incentive Scheme**, which was utilised in DPCR5, benchmarks DNO's network reliability performance in terms of planned and unplanned customer interruptions (CIs) and customer minutes lost (CMLs). DNO performance is compared to the industry benchmark using two years (trailing) historical data with a total exposure of ±250 return on regulatory equity[13] (RORE) basis points per annum. • **Guaranteed Standard of Supply**, which was utilised in DPCR5 with some revisions for RIIO-ED1, provides a means for customers to seek monetary compensation (as defined by Ofgem) from DNOs when they experience sustained outages. • The **Worst-Served Customer** mechanism, which was utilised in DPCR5 with some revisions for RIIO-ED1, provides DNOs with a "use it or lose it" allowance to improve the quality of supply to their worst-served customers. Ofgem provides a total allowance of £76.5m to be shared across all DNOs based on the percentage of total affected customers. • The **Health, Criticality, Risk, and Load Indexes** (secondary deliverables), which were utilised in DPCR5 with the inclusion of criticality in RIIO-ED1, are utilised by Ofgem to: monitor network availability, ensure prudent short- and long-term management of networks, and monitor performance of DNOs in delivering planned targets. The use of these indexes is core to the RIIO model. Rather than taking a hands-on, detailed approach to monitoring (e.g. tracking completion of projects and costs), Ofgem is able to track the performance of these indexes against a DNO's business plan. In doing so, Ofgem provides scope for DNOs to innovate and drive efficiency in achieving these targets without prescribing how targets are achieved. As a secondary deliverable there are no direct incentives around these indexes; however, their performance is tracked as a part of annual reporting and revenue adjustment (as well as being publicly published). Failure to deliver on planned index performance will be addressed in revenue adjustments as a part of this process. • **Resilience** (secondary deliverable), which is a measure of the risk from events in three core areas relating to flooding, black start, and overhead lines faults. DNOs are required to report on their risk exposure in these three areas with the aim of reducing exposure over the price control period. As a secondary output there is no direct incentive applied to the resilience measure; however, given that the reports are published publically there is some reputational incentive to ensure improving network resilience. For more information on Ofgem's reliability and availability incentives see Section 4 of [9] and [12].	

Overview of Efficiency and Innovation Incentives

In addition to the output incentives, Ofgem has established a set of mechanisms to drive efficiency and encourage innovation. While the drive for efficiency and cheaper delivery usually exists in competitive markets, research and innovation often suffer in light of these cost cutting and efficiency measures. Therefore, Ofgem has provided separate incentive mechanisms to encourage progress in both areas.

It is important to note that research funded by the innovation incentives is expected to deliver better, more affordable service for customers. This was highlighted throughout the RIIO-ED1 submission process and cemented at the slow track determination, where Ofgem found that DNOs did not

[13] RORE is defined by Ofgem as, "*The financial return achieved by shareholders in a licensee during a price control period from its out-turn performance under the price control.*"

present sufficient cost savings through innovation. To correct this Ofgem introduced the smart grid saving in its final determination.

Table 3: Overview of Ofgem efficiency and innovation incentives

<table>
<tr><th></th><th>Incentive</th><th>Max Exposure (+ / -)</th></tr>
<tr><td rowspan="2">Efficiency</td><td>Information Quality Incentive (IQI)
Efficiency Incentive Rate (Sharing Factor)</td><td>See incentives</td></tr>
<tr><td colspan="2">Ofgem’s efficiency mechanisms provide an upfront incentive for DNOs to develop efficient business plans (in comparison to Ofgem’s view of efficient costs), and an ongoing incentive to outperform during the price control period. The two efficiency mechanisms are:
The Information Quality Incentive (IQI), which was utilised in DPCR5, encourages DNOs to develop accurate and efficient plans as a part of the regulatory submission process. In it’s simplest form the IQI provides an upfront reward or penalty to DNOs based on the cost and volume efficiency of their proposed plan in comparison with Ofgem’s view. Throughout the price control period if the DNO manages to outperform their TOTEX allowance they are rewarded through the Efficiency Incentive Rate (as discussed below). DNOs that are seen as being more efficient as a part of the IQI assessment are given a higher Efficiency Incentive Rate throughout the price control period.
The Efficiency Incentive Rate (or Sharing Factor) forms a portion of the IQI assessment. It designates the percentage of under or over expenditure (from the TOTEX allowance) that a DNO is exposed to, with the remainder being shared by customers. In the event a DNO is able to deliver their outputs while underspending their TOTEX allowance, they retain a percentage of this underspend. Conversely, if a DNO overspends their TOTEX allowance to deliver outputs, they are required to fund the same percentage of overspend. Therefore the Efficiency Incentive Rate provides a two-sided incentive for DNO’s to outperform their proposed cost allowance through efficiency and innovation, while avoiding overspending. This rate is also an integral part in the calculation for the Annual Iteration Process, which adjusts base annual revenue throughout the RIIO-ED1 price control period.
For the RIIO-ED1 price control period Ofgem has set the efficiency incentive rate between 53-58% for slow track DNOs and 70% for fast track [13]. In the event of significant (unreasonable) under or overspend, Ofgem reserves the right to undertake a re-opener, where the level of under or overspend meets pre-defined thresholds [14].
For more information on Ofgem’s efficiency incentives see Section 9 of [9].</td></tr>
<tr><td rowspan="2">Innovation</td><td>Network Innovation Competition (NIC)
Network Innovation Allowance (NIA)
Innovation Roll-out Mechanism (IRM)</td><td>See incentives</td></tr>
<tr><td colspan="2">Although a number of the previously discussed incentive mechanisms encourage innovation, Ofgem has recognised that there are areas of research and development that may not provide sufficient benefit for DNOs but that may be of benefit to society. Historically, innovation has been funded (in part) through two schemes: the Innovation Funding Incentive, and Low Carbon Networks Fund. These schemes have been replaced under the RIIO model, with Ofgem developing three new incentive mechanisms:
The Network Innovation Competition (NIC), which is an annually awarded, competition-based incentive to promote large-scale research projects that will deliver low carbon or environmental benefit. DNOs can request a maximum of 90% of funding to be provided through NIC, with a total of £90m per annum available for the first two years of RIIO-ED1.
The Network Innovation Allowance (NIA), which is a fixed “use it or lose it” allowance to fund small-scale innovation projects. Funding is allocated on a per license area basis depending on the strength of each DNOs innovation strategy (submitted as a part of their business plan). For RIIO-ED1 Ofgem has awarded allowances between 0.5-0.6% of base annual revenue with a maximum of 90% project funding to be provided from the NIA.
The Innovation Roll-out Mechanism (IRM), which is aimed at enabling the integration of innovations in business as usual. Where an innovation delivers viable and proven low carbon or environmental benefits, DNOs can seek redress for the cost of roll-out through revenue adjustment twice within the price control period. This level of adjustment is limited to 1% average base annual revenue.
For more information on Ofgem’s innovation incentives see Section 10 of [9].</td></tr>
</table>

5.1.3 Lessons Learned

As a number of Australian utilities approach the final stages of their regulatory determination process (for 2014-2019 or 2015-2020) there has been a clear indication by the Australian Energy Regulator (AER) that it will take a hard-line approach with utilities that it believes are over investing in their network or are operating inefficiently. At the end of 2014 the AER published draft determinations for a number of utilities outlining cuts of circa 30-40% to CAPEX and OPEX from that proposed [15]. Although the goal of the AER has always been to promote and encourage prudent and efficient expenditure by utilities, such drastic cuts to proposed business plans indicate that the AER is willing to consider all options at its disposal in achieving this goal. To this end, it is foreseeable that the AER may look to build on its existing set of incentives[14], and adopt or adapt some of those developed as a part of RIIO as a method of incentivising continual improvement.

My experience with the Regulation team and my subsequent research has taught me a great deal about the regulatory environment in the UK, particularly the role of Ofgem and RIIO in driving utilities to reduce prices and incentivise efficient expenditure. Outlined below are some of the opportunities that I see for the Australian regulatory environment and some of the challenges they pose within the UK:

1. The use of fast and slow track decisions to encourage utilities to provide a well developed and lean business plan at first submission. Rewards for receiving a fast track submission should be sufficient to encourage utilities to come with their "best offer first," with criteria that is challenging but achievable.
   The current challenge with this system, given that only one of the six DNOs were successful in receiving a fast track determination, is that if DNOs feel that a fast track determination is unachievable, they may be more inclined to put forward financially conservative business plans in future regulatory submissions.
2. The use of an AIP-style mechanism to encourage utilities to deliver against their business plans year-on-year. This mechanism would also act to "ratchet down" expenditure over time, encouraging efficiency improvements on a more continual basis (rather than the step change as is being seen in the current AER determinations).
   Under this mechanism DNOs in the UK must avoid outperforming TOTEX allowance by under-delivering on planned work (volumes). Doing so would deliver additional revenue in the short-term, but if this is sustained it would be to the detriment of their network and their credibility with Ofgem.
3. The use of defined output measures and targets to monitor (and possibly reward) the performance of utilities throughout the regulatory period. This should be done in a way that is not so prescriptive that it stifles innovation in the delivery of work and targets.
4. The use of direct benchmarking and multiple publicly published leader board or league tables has increased competition between the DNOs, which otherwise have limited incentive to compete. This level of competition has been reflected in UKPN's goal of achieving top third performance amongst the 14 license areas.

Overall, the six core output areas and their related incentives are strongly linked to customer and stakeholder values, ensuring: good customer experience, reliability, value for money, or sustainability. As a means of demonstrating this commitment to customers and stakeholders, UKPN have developed a set of 77 output commitments [16], which will be tracked and reported over the price control period.

Throughout the RIIO-ED1 price control it will be interesting to see the impact of the new model on DNO performance, cost efficiency, and innovation. While the RIIO model is well developed, it remains subject to change. As Ofgem and utilities begin their preparation for the second RIIO price control period it will be interesting to see what (if any) improvements there are to the model.

[14] The AER has four key incentives to promote prudent and efficient expenditure: the Efficiency Benefit and Capital Expenditure Sharing Schemes (similar to Ofgem's Efficiency Incentive Rate), the Service Target Performance Incentive Scheme (a combination of the BMCS, GSop, and IIS), and the Demand Management Incentive.

5.2 Finalising the "Asset Management Manual"

Over the past three months I have continued work on the transition between PAS55 and ISO55000. My main focus during this period has been the completion of the "*Asset Management Manual,*" discussed briefly in my first quarterly report. The purpose of this document is to provide a high level overview of how UKPN manages assets and how their systems and processes are consistent with the requirements of ISO55000.

To ensure that this document (and UKPN's asset management system) meets the requirements of ISO55000, UKPN enlisted the assistance of The Woodhouse Partnership Limited[15] (TWPL). At the time of publishing this document was undergoing review by a number of senior managers within the Asset Management directorate.

In the last week of February UKPN undertook their final annual PAS55 surveillance visit[16]. During this surveillance visit, which extended over two days, representatives from TWPL audited components of UKPN's asset management system to ensure they were compliant with the requirements of PAS55. Some of the elements reviewed included:

- strategy and planning processes;
- operational planning and delivery, focusing on work planned in the 2014/15 financial year, initial volume estimates, and performance to date;
- the use and management of contractors in achieving operational targets;
- the use of suitable change management processes, particularly focusing on the change impact from the Business Transformation Project; and
- asset management related communications to operational staff.

From these audits it was found that UKPN are compliant with PAS55, and were successful in retaining its accreditation with no major non-conformances raised.

As this was the last of UKPN's PAS55-related assessments, focus will now move to the transition to ISO55000. In early March TWPL will build on the work that I completed in my first quarter undertaking and independent gap analysis of UKPN's asset management system. Once completed, this gap analysis will outline any mandatory (non-conformance) or optional areas for improvement for UKPN to address prior to its ISO55000 accreditation. Present expectations are that UKPN will undertake its ISO55000 accreditation visit later in 2015.

5.2.1 Lessons Learned

Documenting the various systems and processes within the asset management system was a challenging but valuable undertaking. Not only does it provide a consolidated single overview of the asset management system, it assisted in identifying possible weaknesses or areas for improvement. In this respect it is important that, following UKPN's accreditation with ISO55000, the "*Asset Management Manual*" does not become stagnant and quickly out-dated. (My concerns regarding the development of documentation for the sake of accreditation was raised in my first quarterly report). If it is to remain a document of value and an accurate reflection of UKPN's asset management system it should remain in development as a part of the review and continual business improvement process.

5.3 Asset Risk and Prioritisation (ARP) – Distribution Transformer Model

I have also continued my work with the Asset Risk and Prioritisation (ARP) tool by documenting the health, risk, and criticality calculations for distribution transformers. This was a substantial body of work, which required the documentation of circa 400 calculations (of more than 1,100 calculations that

[15] TWPL are a leading asset management consultancy based in the UK, but consulting in more than 25 countries internationally. TWPL and their employees were actively involved in the development of PAS55 and ISO55000.
[16] Annual surveillance visits are an ongoing requirement of maintaining PAS55 and ISO55000 accreditation. They supplement the three-yearly certification visits and ensure that certified companies maintain and continue to improve their asset management system throughout the certification period.

make up the ARP distribution model). The final document took the form of an interactive flow chart that shows each step in the calculation from input data (consolidated from a number of corporate IT systems), through intermediate calculations, finally producing indexes for current and future years. This documentation will now form part of the library of ARP models that outlines how UKPN handles calculation of asset health, criticality, and risk for the various types of assets.

In documenting this model I was surprised by the complexity and amount of condition-based data included in the calculation of distribution transformer health index, which incorporates (among other things):

- oil condition (moisture, acidity, breakdown strength)
- oil top-up volume
- loading (duty cycle)
- inspection results
- maximum temperatures
- bushing condition
- housing condition

However, the predominant factor in determining a distribution transformer's health index during its expected life is its age. Beyond the expected life condition factors are more prevalent in calculation of health index. This method of estimation of health index is known as "age modified by condition." In future UKPN plan to incorporate condition and defect data in the calculation of health index during an asset's expected life. This would improve the accuracy of the health index in identifying and prioritising problematic assets. As such, these models have been designed to readily incorporate this additional data and calculation.

Given my work on the distribution transformer ARP model I was also tasked with understanding and verifying development of the fluid filled cable model. A prototype Excel-based model had been developed by UKPN that included oil leakage rates in the calculation of health index. I was responsible for verifying that these changes had been correctly incorporated to the latest version of the fluid filled cable model, as documented in the prototype and agreed development scope.

5.3.1 Lessons Learned

In documenting these calculations I was able to develop a detailed understanding of the ARP distribution transformer model. This understanding reinforced some of the lessons learned from my first quarterly report. In particular, data quality and completeness is vital; without this the output of the model is heavily influenced by generic assumptions. These assumptions erode the ability of even the most complex model to differentiate and prioritise assets for refurbishment or replacement.

I would also question the suitability, complexity, and cost associated with collating condition-based data for such a model, particularly for lower value assets like distribution transformers. In a geographically compact network like the UK, which is dependent on a high reliability electricity supply, collecting this information may be economically justifiable. However, in the less dense more geographically dispersed networks of Australia, collecting this level of data for distribution transformers is unlikely to be cost effective. In this instance, statistical models, which assess groups of assets (e.g. based on historical failure rates), may prove more suitable.

6 Future Works

In the coming three months, my last with UKPN, I will continue my involvement with the ISO55000 transition, with the final PAS55 surveillance and ISO55000 gap analysis visits occurring in the coming weeks. I will also be working with the:

- Network Design Standards team – on the Imperial College of London load related expenditure (LRE) model (discussed in my first quarterly report); and
- Future Networks team – on an innovative project looking at live partial discharge monitoring of power cables.

My work with the Imperial College of London's LRE model will focus predominantly on developments to the Element Energy Load Growth model (named after the consultancy engaged in its development – Element Energy), which forecasts load growth at a secondary substation level based on:

- customer type (commercial, industrial, or residential);
- population, economic and building growth rates;
- developments in technology and energy efficiency; and
- uptake of these new technologies.

I expect that my work in this area will give me an understanding of the LRE and Element Energy Load Growth models, and how such tools can be utilised to understand how changes in customer usage, developments in technology, and changes in economic conditions will impact distribution networks.

My work on live partial discharge monitoring system will be a continuation of research already undertaken as a part of an Innovation Funding Incentive project on online condition monitoring. I will be working to embed the cable monitoring tool within the business, as well as looking for further development opportunities. I expect that my work in this area will give me practical experience with online condition monitoring technologies and the practicality and challenges surrounding their use.

These experiences will be accompanied by a number of site visits to the control centre in Fore Hamlet (that I am yet to visit), to the Imperial College of London, and to UKPN's 6MW / 10MWh Li-ion battery bank in Leighton Buzzard (installed as a part of the Smarter Network Storage[17] project on the Low Carbon Networks Fund).

Outside of work I have continued my travels around the UK and Europe, including visiting the city of Bristol, home a number of feats of engineering like the SS Great Britain and the Clifton Suspension Bridge; as well as welcoming the New Year in Romania. In the coming months I am looking forward to a hiking trip in the Snowdonia Nation Park, and short visits to Germany and Turkey.

I'm also happy to share that since my last report I have secured a nine month placement with ComEd, who own and operate the transmission and distribution network for Chicago and the Northern Illinois area. During the first portion of my nine months with ComEd I will be working as a part of the Smart Grid and Technology team under the supervision of Daniel Gabel (Manager Smart Grid and Technology, Commonwealth Edison). While working in this area I hope to learn from ComEd's experience with smart grid technology[18], particularly with innovative technologies that enable better utilisation of assets and improved network performance. I would like to thank Steve Mockford (Head of Engineering Standards, UK Power Networks) for his assistance in securing this placement. Over the coming months I will finalise my visa and travel arrangements for the United States of America.

I look forward to reporting on my work and lessons learned for the coming quarter.

[17] For more information on the Smarter Network Storage project see http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/.

[18] ComEd are leading in many areas of smart grid research, having established a smart grid test bed to trial new technologies (https://www.comed.com/technology/bringing-innovation/test-bed/Pages/default.aspx) and being active participants in the research collaborative like the Electric Power Research Institute (EPRI).

7 Other Works

This section covers other work or experience undertaken during my time abroad that is of interest but not directly related to my area of research on the E. S. Cornwall Memorial Scholarship.

7.1 Site Visits

During the last quarter I have been fortunate enough to attend a number of site visits to UKPN owned and operated sites in the South-eastern and London license areas. Two of the more notable site visits were:

- multiple secondary (distribution) substations (11kV / 400V) within the city of London; and
- the Guildford Grid Supply Point and Substations complex 123 / 33 / 11 / 6.6kV[19].

The Bank underground station in central London is scheduled to undergo significant development to improve its capacity, finishing in 2021. As a part of this project UKPN have been engaged to ensure that the underground work being carried out in the area will not have a negative impact on their assets. I was able to attend a number site visits to secondary (distribution) substations in the surrounding areas that were aimed at targeting at risk assets (namely cables, cable joints, and connections at risk of damage from subsidence).

These site visits and subsequent discussions with my colleagues highlighted some of the challenges facing DNOs in such a heavily congested and space-poor environment; for example:

- the cost and limited cable access of running LV distribution feeder cables;
- the safety and operational concerns of working in confined spaces, often with limited or impeded access; and
- the direct impact of development in surrounding areas on UKPN's assets.

It was also interesting to see how design standards had changed over time and new technology had been incorporated alongside existing infrastructure to make the network more flexible and safer; for example:

- the safety risks with exposed LV bus and hand operated LV fuses had been mitigated by updating operating practices and using remote switching equipment;
- HV RMUs supplying secondary transformers have been enabled for remote control; and
- the general increase in live monitoring capabilities within these substations;
- and the opportunities and issues with operating a highly interconnected (meshed) LV network like that in London.

The Guildford Grid Supply Point and Substation is connected at 132kV and supplies the 33, 11, and 6.6kV network in the surrounding area. The Guildford complex houses a 132kv switchyard, two 90MVA 132 / 33kV transformers, two 23MVA 33 / 11kV transformers (Guildford A substation), two 24MVA 33 / 11kV transformers (Guildford B substation), one 33 / 6.6kV transformer, and accompanying 33kV and 11KV indoor switchboards. In recent years, UKPN have moved to standardise operating voltages throughout their HV network including the uprating of 6.6kV to 11kV. I was able to attend a site visit to Guildford as a part of the verification of work completed by contractors in converting an existing 6.6kV indoor switchboard to 11kV. While the site was largely similar to any Australian grid (bulk) supply point and substation, it was again interesting to observe how design standards and technology had changed over time. This was especially highlighted when inspecting the substation yard, where a transformer manufactured in 1959 was operating alongside a vegetable oil insulated transformer that had been installed in recent years as a part of an Innovation Funding Incentive Project.

[19] 6.6kV is a legacy voltage within the UK distribution network. Existing 6.6kV network is gradually being phased out in favour of 11kV; however, there are some instances where it is not technically or economically viable to do so. Therefore some portions of network continue to operate at 6.6kV.

7.2 London Array (Wind Farm)[20]

In early December I attended a presentation organised by the Institute of Engineering and Technology (IET) titled "*The London Array – harnessing offshore wind*" focusing on the construction and early operation of the London Array wind farm [17]. The London Array is the world's largest offshore wind farm and is located the Thames Estuary near Kent approximately 50km off of the east coast of England. Table 4 provides an overview of some key facts and figures around the London Array's construction and export capacity.

Table 4: London Array statistics

	Fact	Figure
Build	Construction Duration	2 years (approx.)
	Commissioned	April 2013
	Cost	£1.8 billion
Technical	Turbines	175 × 3.6MW Samsung units
	Turbine Capacity	630MW (previously planned to expand to 1GW)
	Offshore Substations Capacity	Two 33 / 150kV substation platforms, each containing two 180MVA transformers
	Onshore Substation Capacity	Four 150 / 400kV 180MVA transformers
	Power Output	1.12TWh (since March – December 2014)

For more information on the specifications of the London Array see [18].

It was interesting during the presentation to hear about some of the challenges that were faced during the early construction and early operation of the turbines. Some of these points are outlined below:

- The initial plan for the London Array wind farm was for a two phase development, phase one being for the installation of 630MW of wind turbine capacity (completed in April 2013), and the second phase increasing this to 1GW. In February 2014, the London Array consortium announced that phase two would not continue due to technical and environmental challenges, namely the threat to the Red Throated Divers which inhabit the area.
- Reactive power compensation was vital to meet export requirements given the high capacitance of the four 50km 150kV cables that connect the two offshore substations to the onshore transmission substation.
- Have had issues with cables becoming unburied as a result of disturbance by shipping and tidal movement of the seabed. However, to date they have been able to reliably detect exposed sections of cable using fibre optic distributed temperature sensing.
- Historically, wind turbines with gearboxes suffer from lower reliability (as a result of gearbox failure); however at the time of presenting they had only had one gearbox failure.
- The importance of preventative maintenance and condition monitoring was highlighted. The turbines themselves have a number of sensors to monitor for developing issues.
    - Unplanned outages have formed a significant portion of turbine downtime with the split being approximately 50.1% planned outage to 49.9% from unplanned outages.
    - Some turbines have remained out of operation for extended periods following warnings or alarms owing to limited access to the turbines (e.g. as a result of poor weather or tidal constraints).
- Year to date (December 2014) they had achieved 96.01% availability of wind turbines although overall their TWh output for the year to date was down on forecast. This underperformance was largely attributed to milder-than-expected wind conditions.

The presentation provided an interesting overview of the London Array, high-level specification, and performance statistics. Owing to the non-engineering background of the presenters, the presentation lacked technical engineering detail in some instances and this was reflected in questions asked by the

[20] Information reported in this section was documented during the original presentation by Mike O'Hare, et al. Where possible information has been verified against reputable sources; however, information presented in this section should not be reproduced without a corroborating reference.

audience who were obviously interested in the engineering challenges (e.g. issues with intermittency, instability, impact on the grid).

7.3 Future of the Large Hadron Collider

In mid-February I attended a presentation organised by the IET titled "*Large Hadron Collider, the Higgs Particle, and the Future of Big and Small Science?*" that discussed the work being undertaken at the Large Hadron Collider facility. Interestingly, the presentation covered a substantial portion of the detailed physics involved in producing the Higgs boson.

Given the complex nature of the material presented and my limited knowledge in this area, I will not provide an overview of this presentation. However, anyone who is interested in reading more about the Large Hadron Collider or the Higgs boson can refer to a number of online sources, including:

- The Science and Technology Faculties Council (UK) website on particle physics (http://www.stfc.ac.uk/646), which explains the work being undertaken at the Large Hadron Collider facility in language suitable for novice readers.
- CERN's website (http://home.web.cern.ch/topics/large-hadron-collider), which has a wide variety of information on the Large Hadron Collider, including the future upgrades that will enable it to undertake collision experiments at almost twice the energy of that previously capable.
- CERN's publication titled "*LHC: The Guide*" (http://cds.cern.ch/record/1165534/files/CERN-Brochure-2009-003-Eng.pdf), which provides a detailed overview of the Large Hadron Collider (including a background on the relevant particle physics) in language suitable to more experience novices or intermediate readers.

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