E. S. Cornwall Memorial Scholarship

First Quarterly Report

UK Power Networks

1st September 2014 – 1st December 2014

Matthew Zillmann
04/12/2014

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.

Acknowledgements

The author of this report acknowledges the support of UK Power Networks and its employees. Without their support and willingness to share knowledge this report would not have been possible. In particular, the author would like to thank: Barry Hatton (Director of Asset Management, UK Power Networks), Steve Mockford (Head of Engineering Standards, UK Power Networks), Leisha Krandoo (Engineering Standards and Compliance Manager, UK Power Networks), Ian Butler (Distribution Strategy Manager, UK Power Networks) and Prof. Simon Bartlett (Australian Chair in Electricity Transmission, University of Queensland).

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

Table of Contents

1 Glossary, Abbreviations & Definitions

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

Terminology / Acronym / Abbreviation	Definition
"Ofgem"	UK Office of Gas and Electricity Markets
AER	Australian Energy Regulator
ARP	Asset Risk and Prioritisation
Asset Class	A method of grouping assets with similar characteristics for analysis and comparison.
Asset Management System[1]	The term "asset management system" encapsulates all supporting: documentation (e.g. policies, strategies, standards, etc.), information technology systems, processes and procedures that are utilised in managing and deriving value from an organisation's assets (or "things" of value).
BTP	Business Transformation Project
CBRM	Condition Based Risk Model
CCFE	Culham Centre for Fusion Energy
CoF	Consequence of Failure
DNO	Distribution Network Operator
DNV	Distribution Network Visibility
DPCR	Distribution Price Control Review
ED1 (as used in RIIO-ED1)	Electricity Distribution regulatory period 1
EPN	Eastern Power Network (*One of the licensed networks owned by UK Power Networks*)
HI	Health Index
IAM	Institute of Asset Management
ISO	International Standards Organisation
ISO55000:2014	Refers to a suite of documents that comprises the international standard for asset management.
IT	Information Technology
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
LPN	London Power Network (*One of the licensed networks owned by UK Power Networks*)
MAST	Mega-Amp Spherical Tokamak
PAS	Publicly Available Specification
PAS55:2008	Refers to suite of documents that comprises the specification for the optimised management of physical assets.
PoF	Probability of Failure
RIIO	**R**evenue equals **I**ncentives, **I**nnovation and **O**utputs
RTU	Remote Terminal Unit
SPN	South Eastern Power Network (*One of the licensed networks owned by UK Power Networks*)
TNO	Transmission Network Operator
TWPL	The Woodhouse Partnership Limited
UKPN	UK Power Networks

[1] This definition was developed by the author to provide a basic understanding of what is referred to by the term "asset management system". For further explanation, it is advisable to refer to the relevant definitions within ISO55001 or PAS55.

2 Executive Summary

In recent years the Australian electricity supply industry has come under pressure from consumers and stakeholders to stem the trend of electricity price increases. Network charges make up the most significant portion of the price that consumers pay for electricity. As a result, network operators are being asked to evaluate opportunities for efficiency savings and cost reductions. During my tenure on the E. S. Cornwall Memorial Scholarship I hope to explore opportunities for optimising expenditure in the area of asset management.

To assist in this research I will undertake a period of nine months' work at UK Power Networks. UK Power Networks own and operate three of the UK's fourteen distribution service areas (including London's power network). My time at UK Power Networks will be primarily focused on the transition from PAS55 to the recently published ISO55000 series asset management standard. Both of these standards outline the components of an effective asset management system and enforce the need for continual review and improvement. Within the UK, the electricity industry is regulated by a government body known as the Office of Gas and Electricity Markets ("Ofgem"). Ofgem views ongoing compliance with these standards as an indicator of prudent and effective asset management.

My first quarterly report provides an introduction to PAS55 and ISO55000, discussing the key points and differences. It also highlights two other projects that I have gained exposure to. These projects are: the Distribution Network Visibility project, and the Asset Risk and Prioritisation tool. Both projects analyse and present network data in ways that enable intelligent and informed decision making. In my opinion initiatives like these represent valuable opportunities for the Australian electricity supply industry; particularly in circumstances where poorly managing assets can result in millions of dollars of additional cost either through lost opportunity or over investment.

My work understanding UK Power Networks' implementation of PAS55 and the subsequent gap analysis for ISO55000 has reinforced that UK Power Networks have a well-developed asset management system. Their effort continually challenging and developing this system is important, particularly in today's changing power systems environment. In considering how these standards more generally I was cognisant of the possibility that:

- Achieving accreditation with either standard poses the risk of creating documentation (and in some instances processes) that deliver little or no benefit to the organisation. Organisations should critically review the requirements of each standard, paying particular attention to areas that provide foreseeable benefit.
- There is a common perception that an organisation which is PAS55 or ISO55000 accredited is by inference a "good" asset management business. I propose that this is not the case. PAS55 and ISO55000 outline the high-level requirements for asset management. While not desirable, it is possible that an organisation could meet these requirements and not be a highly performing asset management business.
- In my opinion, the generalisation from PAS55 (that is targeted at the management of physical assets) to ISO55000 (that is targeted at all assets) dilutes some of the value of the asset management standard. Developing a document that can be applied to a wider variety of industries, particularly those dealing with non-tangible assets, has resulted in requirements that are broad and open to interpretation. Therefore, I suggest that, although PAS55 has been superseded by ISO55000, it should still be viewed as a valuable reference for the power industry.

As a part of performing a gap analysis for the transition from PAS55 to ISO55000 I became aware of a number of innovative projects that UK Power Networks is undertaking. The first of these was the Distribution Network Visibility project. The core focus of this project was to investigate improvements in the capabilities of network monitoring devices, looking especially at how data from these devices can inform decision making. Tools developed included, but were not limited to the:

- Development of a detailed library of secondary (distribution) substation load profiles. Using this library of load profiles, each secondary (distribution) substation within the study area was categorised (e.g. residential, commercial, industrial, mixed). This information was used in a variety of ways; for example to:
    - simplify and expedite assessments for minor customer connections;
    - understand how customer load profiles change over time, particularly as a result of new technologies;
    - understand how customer types are clustered geographically; and
    - better target demand reduction or demand management opportunities.
- Investigation of real-time load flow modelling for use in network operations, or more generally, improving the load allocation of existing network models.
- Development of dynamic rating models for secondary (distribution) substations. The availability of this information allowed for more flexible operation of the network. It also provided an understanding of the loss of life resulting from overloading transformers and, if tracked for a period of time, may provide a prudent method for estimating the remaining life of distribution transformers.

Since being trialled on the Distribution Network Visibility project, many of these tools are being further developed for future embedding in UK Power Network's asset management systems and processes.

The second project that I gained exposure to was the Asset Risk and Prioritisation tool (an enhanced version of the more widely known Condition Based Risk Management tool). This tool combines asset information, expert experience, and condition data to predict the health ranking (or health index) and remaining life of an asset. Using the end of life of each asset and the asset criticality, the tool develops an optimised asset replacement or refurbishment program. For UK Power Networks, this information is used twofold: to ensure that the asset refurbishment and replacement program provided to Ofgem is founded on sound engineering knowledge, and to ensure that the available funding is allocated to the area of greatest value (i.e. achieving the greatest risk reduction). This system and its methodology has been recognised in the UK and internationally as world-leading.

As a regulatory tool, Ofgem is driving development in this area to ensure prudent investment in assets. Moreover, it provides a means for understanding the health, criticality, and resultant risk exposure of an organisation's assets. To this end, Ofgem has required that the UK distribution network operators collaborate on a consistent method for classifying health and criticality scores. As one of the organisations leading development in this area, the methodology utilised in UK Power Networks' Asset Risk and Prioritisation tool is seen as an impartial and analytical way forward. Once achieved, this uniformity in methodology will allow for inter-organisational benchmarking of expenditure and resultant risk reduction. Given the improved visibility and accountability that this offers Ofgem, it is foreseeable that the Australian Energy Regulator may impose similar requirements on Australian utilities.

From my experience thus far, it is evident that improved data quality and availability is a fundamental enabler for prudent asset management. As historically low-tech power grids become data enabled, network operators will have greater visibility of their assets, their operating environment, and how they are performing. To realise the true value of this data, it is essential that organisations invest in tools and techniques that create usable information. It is this information that will assist organisations in reducing or optimising capital and operating expenditure on assets.

This report will explore PAS55, ISO55000, parts of the Distribution Network Visibility project, and provide an overview of the Asset Risk and Prioritisation tool and its methodology. In each instance I have summarised my learnings and opportunities and how they might be of value to the Australian electricity supply industry.

In the coming months I will continue my work on UK Power Networks' transition to ISO55000 accreditation while also undertaking placements within Strategy and Regulation, Network Design Standards, and on the Business Transformation Project.

3 Introduction

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][2].

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; and
- A North American owner and network operator – I am currently in discussions with a number of network operators from Canada and the United States of America. I hope to secure my second placement by the end of January 2015.

This document is the first of six quarterly reports that will be compiled throughout my placements on the scholarship. It covers the first three (of a total nine) months that I will spend at UKPN based in Crawley, Sussex, England.

In the first three months of my placement with UKPN I have worked within the Engineering Standards and Assurance team, who are responsible for audits and compliance against PAS55:2008. My core work over this period has been to:

- develop an understanding of the integration of PAS55:2008 within UKPN;

[2] *For indicative purposes only*, over the same period the UK saw a circa 15% increase in the price of domestic electricity (calculated form [20]) with 16% of this price consisting of distribution and 4% of transmission charges (excluding taxes) [21].

- perform a gap analysis for the transition from PAS55:2008 to ISO55000:2014; and
- work with a small team of consultants from The Woodhouse Partnership Limited (TWPL) on the scoping and development of an "Asset Management Manual" for UKPN.

From this high-level review of the asset management system I have identified two additional asset management-related projects that I believe are industry-leading. To this end I sought additional experience working with:

- the Distribution Network Visibility (DNV) project; and
- Asset Risk and Prioritisation (ARP) modelling.

The following report will outline the observations from my first three months at UKPN providing an overview of core concepts, my lessons learned and areas that I see benefit for the Australian electricity supply industry.

4 Background

4.1 UK Power Networks (UKPN)

UKPN is a privately owned DNO that manages three of the fourteen service areas in the UK: Eastern Power Networks (EPN), London Power Networks (LPN), and South Eastern Power Networks (SPN) (as shown in Figure 1). These service areas encapsulate 29,000km^2 of the UK, providing electricity to 8.1 million customers, via almost 186,000km of overhead lines and underground cables [2].

Figure 1: Distribution network areas of the UK, highlighting UKPN's service areas [3]

In 2013 UKPN's regulated asset base was valued at £5.23 billion (depreciated value), with capital and operating expenditures of £632.5 million and £440.3 respectively. Of the £632.5 million in capital expenditure, £115.1 million related to reinforcement work while £320.1 million related to asset replacement [2].

This expenditure is regulated by the Office of Gas and Energy Markets ("Ofgem"), who are responsible for determining the allowable revenue of monopolies operating in the UK electricity and gas market. The present regulatory period, known as Distribution Price Control Review 5 (DPCR5) (1st April 2010 to 31st March 2015) is due to expire in 2015 and will see a significant change to the regulatory model applied to the aforementioned monopolies. Historically, Ofgem have used a variation on the retail price index model, known as RPI-X (a similar concept to consumer price index); however from 2015 Ofgem will be changing to the "Revenue equals Incentives, Innovation and Outputs" (RIIO) model. The RIIO model is aimed at driving network operators to [4]:

- put stakeholders at the heart of their decision making process;
- invest efficiently to ensure continued safe and reliable services;
- innovate to reduce network costs for current and future consumers; and
- assist in delivering a low carbon economy and wider environmental objectives.

UKPN were unsuccessful in securing a "fast-tracked" application for RIIO-ED1 (RIIO-Electricity Distribution regulatory period 1) in February 2014 and recently finalised their second submission to Ofgem. Ofgem's final determination was returned at the end of November 2014 and resulted in a circa 10% reduction in expenditure compared that proposed in UKPN's initial submission.

4.2 UK Regulation and Asset Management

Ofgem's overarching remit is to, "protect the interests of existing and future electricity and gas consumers." Historically this required that Ofgem take a "hands-on" approach to ensuring prudent expenditure and operation in areas including asset management. In an effort to standardise best-practice lifecycle management of assets, the British Standards Institution (BSI) published PAS55, the specification for optimal management of physical assets, in 2004 (PAS55:2004).

This standard was adopted by a number of UK TNOs and DNOs on a voluntary basis as a catalyst for reviewing and improving their asset management practices. However, circa 2006 Ofgem provided strong guidance that utilities should aim to achieve PAS55 certification by April 2008 [5], making it the de facto standard for asset management. This enabled Ofgem to take a "hands-off" approach and placed the onus on utilities to achieve and maintain PAS55 accreditation.

Subsequently PAS55 has been reviewed and updated in 2008 (PAS55:2008). More recently it has been superseded by the International Standards Organisation (ISO) 55000 series of standards, which were released in January 2014. As the new standard for asset management, many organisations are working to transition to ISO55000 compliance, UKPN included.

The following section provides a brief overview of the two standards and their requirements.

4.3 Industry Standards for Asset Management

Organisations that utilise assets in their day-to-day business will undertake asset management in one form or another. Highly performing organisations are those that are actively aware of the asset management challenges they face and work to derive the greatest benefit (be that income, efficiency, or quality of service) from their assets. PAS55 and ISO55000 offer guidance to achieving a well-developed asset management system.

4.3.1 Publicly Available Specification 55 (PAS55)[3]

Developed by the Institute of Asset Management, with leadership by stalwarts of the UK industry and participation from 10 countries, PAS55 deals specifically with the management of physical assets. The standard comprises of two parts, PAS55-1 is the "Specification for the optimised management of physical assets," and PAS55-2 is the "Guidance for the application of PAS55-1."

PAS55 is underpinned by two principles: "line of sight," and the "plan, do, check, act" cycle. The first of these, "line of sight" is aimed at developing a clear and consistent set of goals. All aspects of the asset management system should have clear linkage to a core set of goals or business objectives. Performance measures should then be derived from, and directly mapped to these objectives (as demonstrated in Figure 2). The second principle, the "plan, do, check, act" cycle recognises the need for continual evolution of the asset management system. Development of a highly performing asset management system requires a process of conscious monitoring and review, particularly in adapting to new challenges. Figure 3 shows the "plan, do, check, act" cycle and how the 28 requirements of PAS55-1 align with this cycle.

[3] For the purpose of this report PAS55 will be referred to as a standard, rather than a specification.

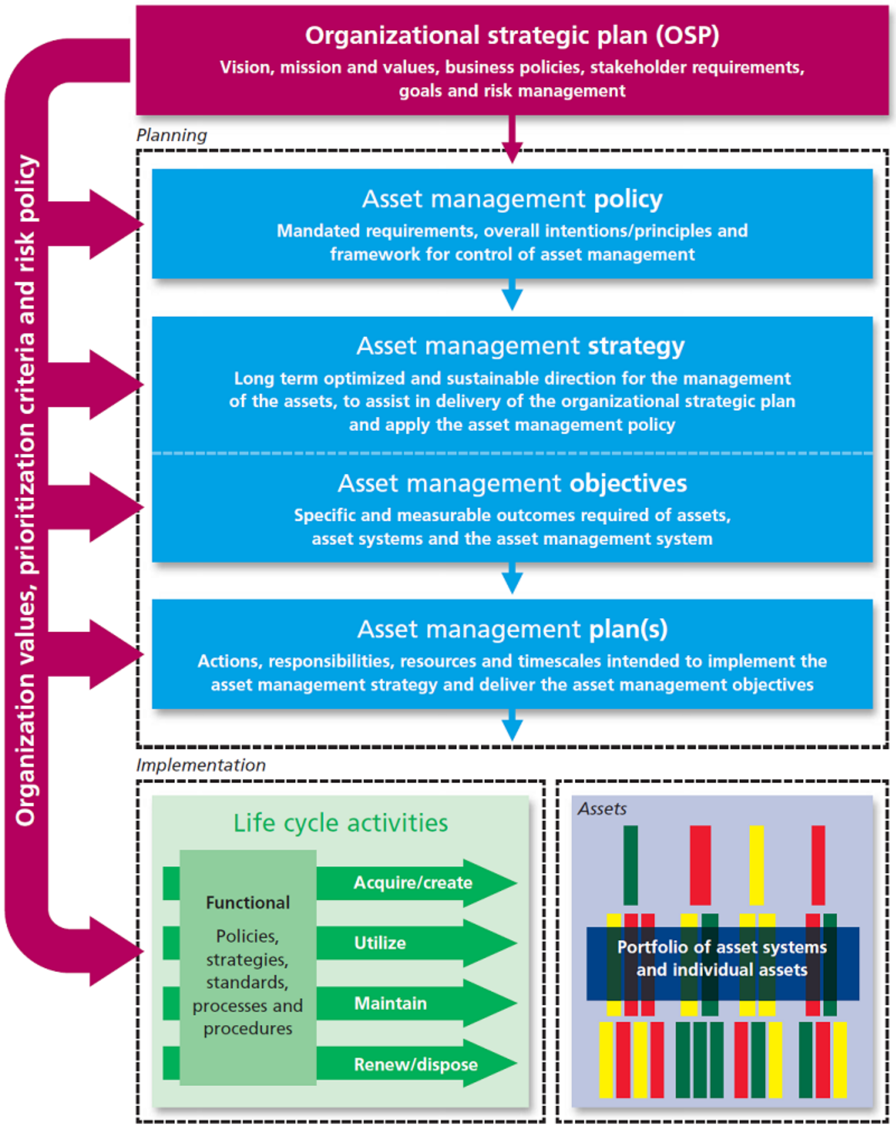


Figure 2: Overview of elements of an asset management system [6]

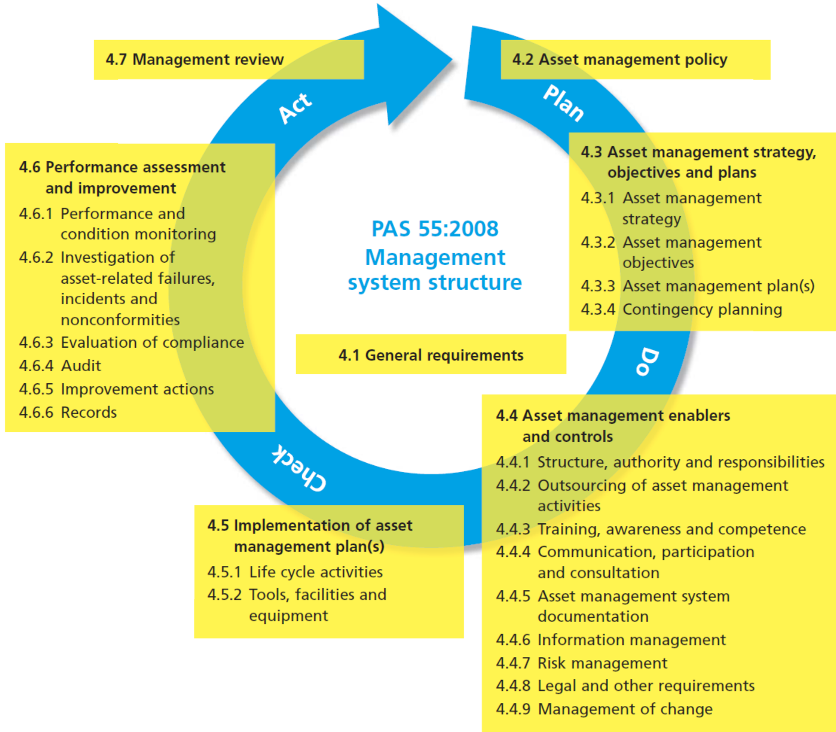


Figure 3: Plan, do, check, act cycle and PAS55-1 requirements [6]

4.3.2 International Standards Organisation 55000 (ISO55000)

Built on the success of PAS55 with input from 31 countries, ISO55000 was first released in January 2014. In addition to aligning to the new ISO document structure, the scope of ISO55000 was broadened to encapsulate all assets, not specifically physical assets. As a result this standard places more emphasis on: understanding stakeholder expectations and requirements (both internal and external to the business) and hence the organisational objectives; the roles of business leaders; and the various facets of risk related to an asset management system. The final format is a similar, but slightly different, set of 29 requirements in seven sections, covering the end-to-end development of an asset management system. Figure 4 outlines these requirements and how they fit within the structure of the asset management system. While ISO55000 does not explicitly refer to the same “plan, do, check, act” cycle or “line of sight,” both of these principles remain heavily embedded within the ISO55000 methodology.

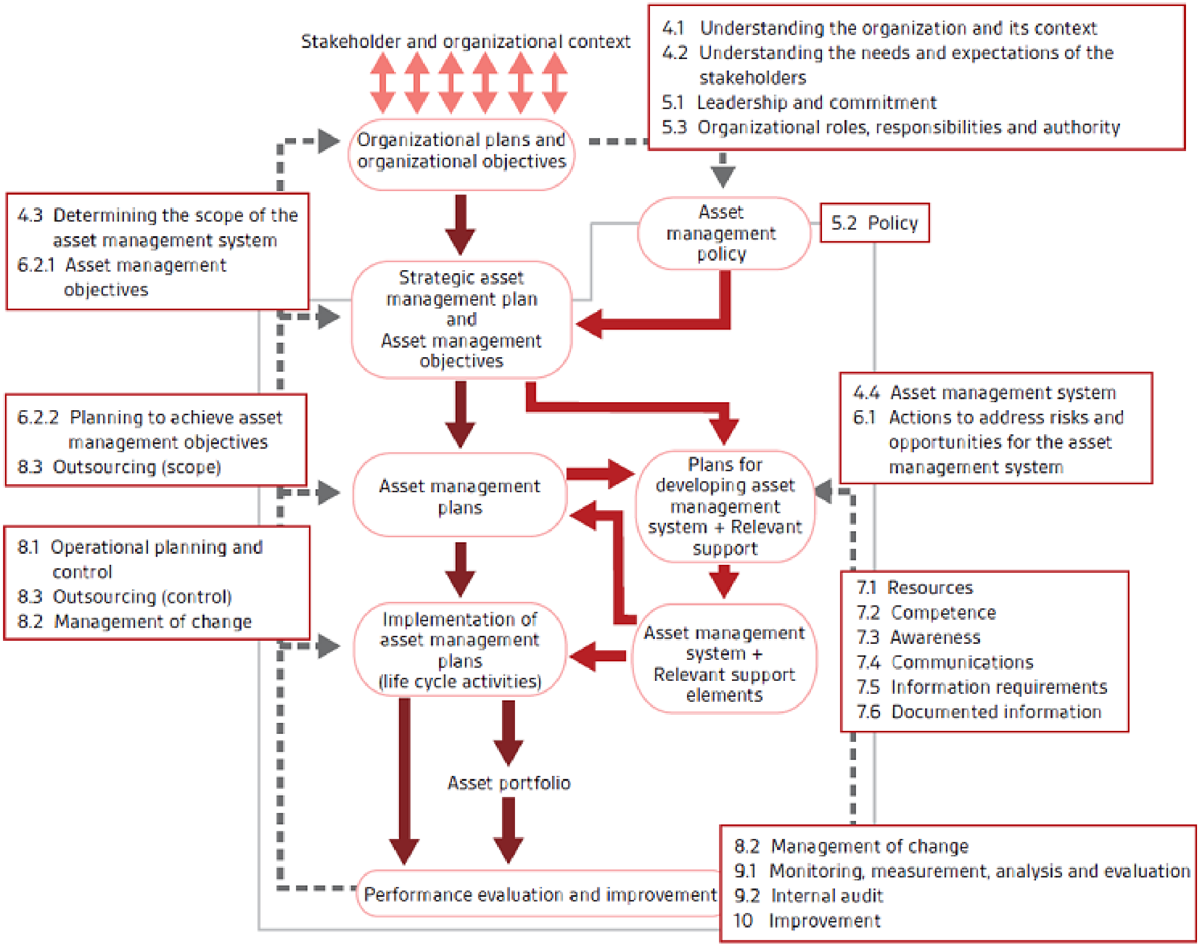


Figure 4: Sections and requirements from ISO55000:2014 [7, 8]

5 Placement Experience

The following section is an overview of work that I have completed and experience gained. Where possible I have drawn comparisons to how my experience may be of value to the Australian electricity supply industry.

5.1 Understanding PAS55 within UKPN

As an organisation with PAS55:2008 accreditation since 2006, my first task at UKPN was to understand how PAS55 has been applied within UKPN's asset management system. I was also fortunate enough to have access to documentation from past (annual) surveillance and (three yearly) accreditation audits. These documents provided a critical and constructive review of the UKPN's asset management system, identifying strengths and weaknesses in their application of PAS55. It was evident from this review (and from past audits) that UKPN is well developed in the field of asset management, achieving recognition as "industry leading" in certain areas. However, it was also evident that there were some opportunities for improvement[4].

5.1.1 Lessons Learned

PAS55 and its underlying principles are well entrenched in UKPN's asset management system. This is reflected in UKPN's reputation as a world-leader in many areas of asset management. Even with this level of certification it is encouraging to see that UKPN are continually working to review and improve their asset management system.

More generally, when reviewing PAS55 I became cognisant of how the standard might be ineffectively applied, eroding the benefits that it was designed to deliver. Particularly in organisations with existing asset management systems where accreditation is mandated (e.g. by a regulating body), there is the distinct possibility that PAS55 accreditation (or ISO55000 for that matter) could be achieved in a "bolt-on," least effort manner. To realise the benefit of PAS55 or ISO55000 the accreditation process should be utilised to critically review the asset management system. Moreover it should:

- ensure that all components of the system are adding value and are working as planned;
- identify components of the system that are not adding value; and
- identify any gaps within the system where value can be obtained.

Organisations should avoid the creation of documentation, systems, or processes *purely* for the purpose of accreditation. It is important that all components of the asset management system are actively utilised within the business and add benefit.

5.2 Understanding ISO55000 and Gap Analysis

The publication of ISO55000 in early 2014 signalled the retirement of PAS55 as the de facto standard for asset management. Since this time UKPN have been preparing for accreditation to ISO55000 and are utilising the opportunity to undertake a holistic review of their asset management system. The first stage in the transition to ISO55000 required an honest evaluation of their existing asset management system to identify gaps or possible improvements. This was the first major task of my time at UKPN. Using input from past surveillance and accreditation visits and my high-level review of the existing system as a basis, I worked through the requirements and guidance for ISO55000 identifying any areas for concern. In completing my gap analysis I undertook reviews in three areas:

1. High-level documentation (including strategy and policy documents)
2. Detailed documentation (covering planning, processes and standards)
3. IT systems

I also engaged with a number of representatives across the organisation to understand the contribution of various systems and processes to the asset management system as a whole. This

[4] For reasons of confidentiality I am not able to elaborate on these findings in great detail.

included seeking assistance of TWPL, a leading asset management consultancy whose employees were active in the development of PAS55 and ISO55000. UKPN have enlisted TWPL's expertise in this area to assist in their transition to ISO55000 accreditation.

As is discussed in [8], organisations that have already achieved or who are well on their way to PAS55 accreditation should not undergo significant change to achieve accreditation with ISO55000. However, the nuances of ISO55000 may require changes to supporting documentation and systems at a high level. This was congruent with my findings and resultant recommendations for changes to UKPN's asset management system, which included:

- Undertaking a review and consolidation of UKPN's strategic documentation.
  - UKPN's existing high-level strategy documents were well-developed, but it was evident that there was some level of duplication and inconsistency inherent in these documents as they had evolved over time. (This finding was supported by feedback from recent surveillance visits.)
- Further development of the documentation of stakeholder requirements and decision making criteria.
  - This work will be incorporated in the creation of the "Asset Management Manual," which is being developed with the assistance of TWPL.
- Improving risk tracking to ensure that all risks relating to the asset management system are recorded in UKPNs enterprise risk tool.
- General updating of documentation and UKPN's intranet to align with the format of ISO55000.

In almost all instances the recommendations made are easily achievable by reviewing and updating existing systems and documentation. Some of the strengths of UKPN's asset management system included:

- The Network Asset Management Policy (NAMP), which is an exhaustive suite of documents that covers all aspects of UKPN's asset related work (by license area) for the coming 10 years.
- The Asset Stewardship Reports, which is a suite of documents detailing the condition and performance of core asset groups and UKPN's strategy for their inspection, maintenance, refurbishment, and replacement.
- IT systems and advanced analysis. Following the completion of the Business Transformation project UKPN will have a world-class set of IT systems as a foundation from which to manage and analyse their assets.

When completing my gap analysis (and as a general reference) I found the following sections of ISO55000 particularly valuable:

- 4.1 Understanding the organisation and its context;
- 4.2 Understanding the needs and expectations of stakeholders; and
- 4.3 Determining the scope of the asset management system.

While these clauses deal with high-level detail, they are core to determining an organisation's objectives (including stakeholder requirements and expectations) and how they plan to fulfil these. Failure to understand these drivers will likely result in an asset management system that is inefficient or ineffective.

5.2.1 Lessons Learned

After working to understand the detail of ISO55000 I am concerned that it does not *necessarily* enforce or imply "good" asset management. As with PAS55, ISO55000 outlines the fundamental components and underlying processes in establishing an asset management system. The broadening of scope and generalisation from PAS55 to ISO55000 has resulted in a less prescriptive set of requirements that, in some instances, are difficult to apply meaningfully. The onus to interpret and apply these requirements in a way that would constitute "good" asset management is largely placed on the organisation itself. In the words of John Woodhouse (Managing Director, The Woodhouse

Partnership Limited and Chairman, and Experts Panel, Institute of Asset Management) who was involved in the organising committee for ISO55000 (ISO PC251) [9]:

> "*ISO 55000 is the first worldwide attempt to capture the generically applicable 'must do' items for the management of any asset type. It does not, however, attempt to define the 'how to', as this depends on organisational context and the assets to be managed. We can therefore expect a rapidly expanding range of industry sector and asset-type guidance material to emerge over the coming years, interpreting and applying the requirements of ISO 55001 in different circumstances. It is likely, for example, that PAS 55 will continue to be popular as expanded guidance on the management of physical assets.*"

This broadened scope also provides grounds for interpretation by auditors and auditing bodies. To assist in consistent interpretation, auditing organisations assessing against ISO55000 must themselves comply with ISO17021-5:2014 "Requirements for bodies providing audit and certification of management systems." This standard stipulates that assessors and assessing bodies must have asset management knowledge relevant to the organisation(s) that they are assessing. In this respect, input by auditors during accreditation and surveillance visits should drive the development of "good" asset management practices, rather than being a checklist assessment. I see this being a possible improvement over the PAS55 accreditation process, which did not have the same domain knowledge requirements imposed on assessors.

At an organisational level, there is a risk that responsibility for the success of the asset management system is confined to the "Asset Management" portion of the business. One of the strengths of ISO55000 is that it highlights (and indeed enforces) the need for collaboration across many areas of the organisation (e.g. HR, Operations, Asset Management) and that each have a stake in achieving the asset management objectives.

From my review of UKPN's asset management system, the areas in which I have seen significant innovation have been in the capture of data and how it is analysed to inform decision making. Two innovative projects that I have become aware of and had exposure to are:

- the Distribution Network Visibility (DNV) project; and
- Asset Risk and Prioritisation (ARP) modelling.

With advances in technology and communications, data (e.g. information about assets, their performance, and the performance of the network) is becoming readily available. Data by itself presents little value to a business; indeed, if used inefficiently or ineffectively it could result in additional burden and wasted effort. For this reason it is important that data requirements are identified (one of the requirements of ISO5500) and utilised to develop information and knowledge. Figure 5 highlights this transition from data to knowledge, demonstrating the value added using the Data, Information, Knowledge, Wisdom (DIKW) Hierarchy [10]. The DNV project and ARP model are specifically aimed at achieving this jump from data to information and knowledge. These works will be discussed in more detail in the following sections.

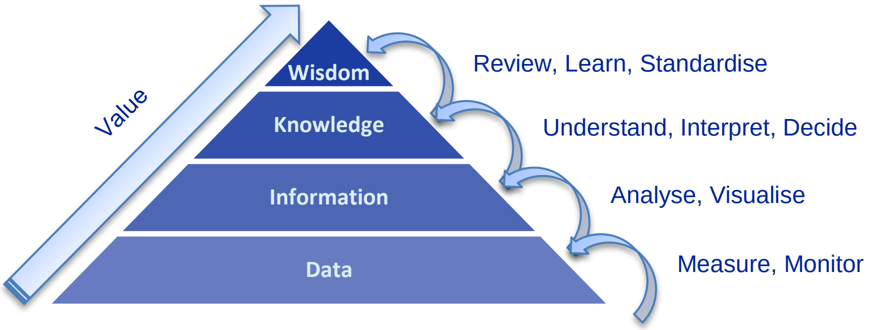


Figure 5: DIKW Hierarchy [10]

5.3 Distribution Network Visibility (DNV)

The Distribution Network Visualisation (DNV) project was established in September 2010 with funding from the Low Carbon Networks Fund (LCNF) and the Innovation Funding Incentive (IFI) scheme[5]. The experimental phase of the project was completed in September 2013 and UKPN are now working to incorporate DNV into "business as usual" systems. The aim of the initial research phase was to:

- improve utilisation of existing monitoring systems (remote terminal units (RTUs));
- explore various data sources and monitoring systems, investigating collection methods and frequencies;
- understand the benefits that could be derived from the analysis and visualisation of this data; and
- use "smart" software packages to better understand network performance.

Figure 6 provides an overview of the work undertaken by UKPN and their project partners PPA Energy and Capula. The project focused initially on documenting high-level user requirements and deconstructing these into data sources and monitoring requirements. The end result is a library of valuable tools and reports that deliver benefits to the business by enhancing: decision making, modelling capability and accuracy, and the understanding of network performance.

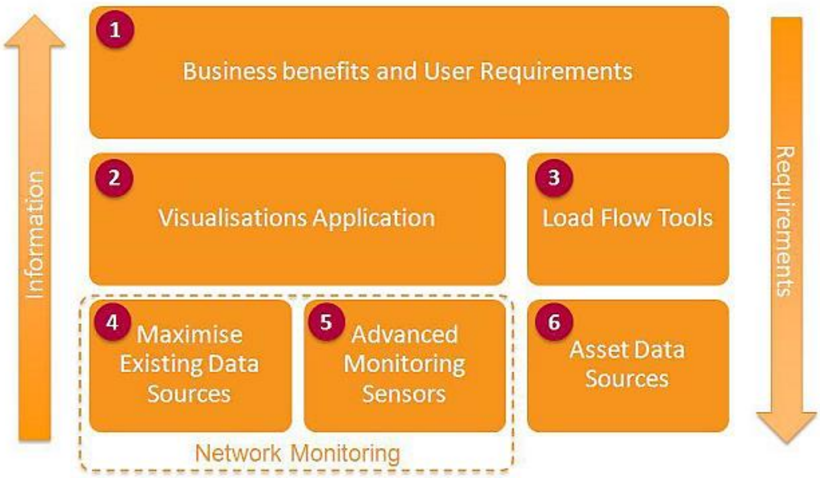


Figure 6: Areas addressed in the DNV project [11]

[5] The LCNF and IFI are two funding incentives established by Ofgem to promote innovation within the UK's highly competitive electricity distribution industry. LCNF is specifically targeted at research to enable the uptake of low carbon and energy saving technologies; while the IFI (which will be replaced by the Network Innovation Allowance (NIA) in 2015) is targeted at innovation in all aspects of electricity distribution. For more information on these incentives see Ofgem's Distribution Network Innovation website (https://www.ofgem.gov.uk/electricity/distribution-networks/network-innovation), or for information on projects covered under these schemes see the ENA 'Smarter Networks' Portal (http://www.smarternetworks.org/).

Given the breadth and depth of research undertaken in the DNV project, it was not practical to have an in-depth understanding in all areas covered (nor did all research fall within the scope of my scholarship's research topic). For this reason I have only reviewed a portion of the work completed under the DNV project. More information regarding key findings and supporting documentation is made available on UKPN's website [12].

5.3.1 Network Monitoring

UKPN's power system is monitored and controlled via RTUs at all primary substations (132/11kV, 33/11kV) and, within LPN, at approximately 45% of secondary substations (11kV/415V) [11]. This level of existing monitoring and control capability within the LPN licence area made it the ideal test location for many of the DNV project's monitoring initiatives.

Historically, data made available from these secondary substation RTUs was limited by the capability of telecommunications infrastructure; however, modern telecommunications and data storage have allowed for the transfer and storage of large amounts of information. To this end, circa 10,000 secondary RTUs were upgraded to report 10[6] new network measurements, making a total of 14 measurements. The measurements captured were[7]:

1. Apparent (S) power
2. Red Phase voltage
3. Power Factor (PF)
4. Substation ambient temperature
5. *Red Phase current*
6. *White Phase current*
7. *Blue Phase current*
8. *White Phase voltage*
9. *Blue Phase voltage*
10. *Real (P) power*
11. *Reactive (Q) power*
12. *Total Harmonic Distortion – Red Phase*
13. *Total Harmonic Distortion – White Phase*
14. *Total Harmonic Distortion – Blue Phase*

Note: For clarity, white (or B) phase is historically known as yellow phase in the UK; although UK wiring standards were updated in 2004 to match the European Union (IEC 60446) convention.

These additional measurements were derived following a period of consultation within the business to understand requirements and resulting benefits. Using this increased monitoring capability and consolidated data from existing systems (e.g. SCADA and the asset register), a number of tools and analysis techniques were explored.

"Advanced" monitoring systems and sensors were also investigated as a part of the DNV project; however, I will not cover these in detail in this report.

5.3.2 Knowledge and Information from Data

As outlined in Section 5.2.1 and Figure 5, simply collecting this additional data would provide little (if any) benefit to the organisation. Further analysis, reporting and understanding was required to generate usable information and knowledge. Some of the areas that UKPN investigated were:

- the development of a visualisation tool in partnership with Capula;
- load profiling (at a secondary (distribution) substation level);
- improved / real-time load flow modelling; and
- dynamic rating of assets.

Data quality was also raised as a concern in the early stages of the DNV project. Given the scale of additional data generated, automated scripts were developed to assist in highlighting and resolving data errors. This will not be covered in this report, but is available in Section 5.3 of [11].

The Visualisation Tool (DNV Application)

[6] Reference document [11] notes that there are 11 new analogues recorded; however, reviewing the analogues I believe the red phase voltage has been double counted. Therefore, there are only 10 previously unavailable measurements added.

[7] Added measurements in highlighted in *italics*

The visualisation tool, aptly named the "DNV Application" was initially prototyped by UKPN but later redeveloped by a consultancy as a web-based tool. The core of the DNV Application is a geographical view of the network. This view is overlaid with dynamically generated reports and analysis. A large suite of reports were also developed that allowed users to view and analyse data in a variety of ways; from raw data timescale charts to load duration curves, calculated load at risk and planning reports.

As a business tool, the DNV Application is still evolving; however it has demonstrated how improved data availability can be leveraged to produce useful information that is of benefit to the business. With further development and integration it presents opportunities for streamlining processes, informing planning and operation, and improving the understanding of how the network is performing. For asset management, the availability of this information will enable more informed decision making to drive investment in areas of greatest need.

Load Profiling

Daily loading data was utilised to develop "normal" load profiles for each secondary transformer with sufficient metering capability. These load profiles were classified using the K-means clustering algorithm as one of the following types: residential, commercial, industrial, mix (residential and commercial), or night-peaking. Once a library of standard, normalised load profiles was developed these were used for different applications. In particular, this information allowed for better utilisation of transformer capacity. Instead of applying an assumed diversity figure for new connections, load profiles (depending on the type of connection) could be used to directly model the impact of new load on a transformer's load profile. Furthermore, documentation of the load profile over time will allow for the identification of changes to customer consumption and usage trends, particularly within a geographical location. This information is particularly valuable as it will assist in understanding how advances in technology are impacting customer usage.

Improved / Real-time Load Flow Modelling

The availability of secondary substation loading data in near real time provided an opportunity for improving the accuracy of load flow modelling and the investigation of "real-time" modelling. To enable this functionality, UKPN investigated two commercial load flow tools: *GE Distribution Power* low and *CGI DPlan* with varying levels of success. In both instances, software limitations restricted the accuracy of the final solution[8]. This highlighted the need for end users (i.e. DNOs) to work with software developers to ensure that products are providing the required functionality. The final finding was that improving load flow accuracy and achieving real-time modelling was a promising prospect, but that it was not economical at present.

Dynamic Rating of Assets

The improved data availability achieved during DNV project resulted in the opportunity for dynamic rating of distribution transformers being investigated[9]. While dynamic rating is not a new practice for high-value primary assets (e.g. power transformers or high criticality cables), it does not normally occur with lower value assets (e.g. distribution transformers). Dynamic rating of distribution transformers would deliver obvious benefits for network operations, allowing short-duration overloading of transformers during a contingency or load transfers with an acceptable loss of life. In addition, asset management would benefit if this was monitored over a long duration. The resulting history could provide an estimate of the remaining life (or condition) of a transformer. This would assist the prioritisation of asset replacement, particularly when considering that low-value assets typically don't receive the same level of monitoring, testing and maintenance as their high-value counterparts.

[8] See Section 5.5 of reference document [11] for more information on the issues experienced with the load flow software.

[9] See Section 5.8 of reference document [11] for more information on the dynamic rating model applied to secondary transformers.

5.3.3 Lessons Learned

The DNV project provides a good example of how data can be leveraged to improve understanding of network performance and drive informed decision making in asset management. Given the dispersed nature of much of Australia's network it's not feasible to expect the same level of communications and monitoring capability for secondary (distribution) substations as that seen in UKPN's LPN distribution area. However, the rollout of "smart meter" technology may provide some of this functionality, particularly in understanding the distribution of load and how the network is performing. DNOs should exploit this opportunity by influencing smart meter development and implementation to ensure the required functionality is achieved.

I was particularly impressed by the application of high-granularity load profiling. The availability of this information at a customer level (e.g. at the point of metering) would enable a detailed understanding of low voltage distribution asset utilisation; particularly when assessing new connections and identifying target areas for demand management. This would also allow for the early identification of changes in usage trends. UKPN observed changes in secondary substation load profiles within the relatively short duration of the DNV project. These changes in load profile are expected to continue with the migration to low carbon distribution networks. Given the challenges that Australian DNOs are facing with a changing customer environment, this information would be useful in ensuring that DNOs provide a service that is congruent with customer's usage needs.

Device monitoring is becoming a standard feature of many primary power system assets. Add to this the number of third-party monitoring and field data capture devices now available and it is evident that data availability will not be a challenge for the DNO of the future. Rather the challenge will be rationalising the copious amounts data and transforming it into usable information that empowers organisations to make informed decisions.

5.4 Asset Risk and Prioritisation (ARP)

The second major task that I have undertaken involved: understanding the implementation of Asset Risk and Prioritisation (ARP), developing detailed documentation of the model for distribution transformers, and providing general input and assistance with various aspects of the ARP model. This tool, which was developed by EA Technology Limited[10] and customised for use within UKPN, is an extension of the Condition Based Risk Management (CBRM) tool[11]. Its core goal is to provide an integrated, database-driven application to model asset condition related risks which can be used to optimise network investment.

Given the commercially sensitive nature of components of this work, I am not able to discuss the specific details of the ARP and related calculations. However, the following section will provide an overview of the components of the model and their importance in developing an optimised asset replacement and refurbishment program.

5.4.1 Overview of the Model

The ARP / CBRM model applies ranking indexes to the different aspects of asset health, and criticality and combines these into an overall priority ranking. The goal of these rankings is to provide an objective assessment of how limited funding can best be utilised to mitigate risk. The ARP process to optimise asset investment is outlined below in Figure 7. There are five key stages in this process:

1. Calculation of the asset health in relation to a defined health index (HI)
2. Calculation of the probability of failure (PoF)

[10] EA Technology Limited (formerly the Energy Research Council Centre) was founded following the privatisation of the previously nationally owned electricity network, which began in 1990. They are well known for internationally for their work in the field of asset management, particularly in understanding the condition of assets and optimising investment in asset maintenance and replacement.
[11] See http://www.eatechnology.com/products-and-services/optimise-network-operations/cbrm for more information.

3. Modelling future degradation of asset health
4. Calculation of asset PoF over time, identifying the optimal intervention time
5. Optimisation of the asset refurbishment or replacement program (across all assets) using criticality

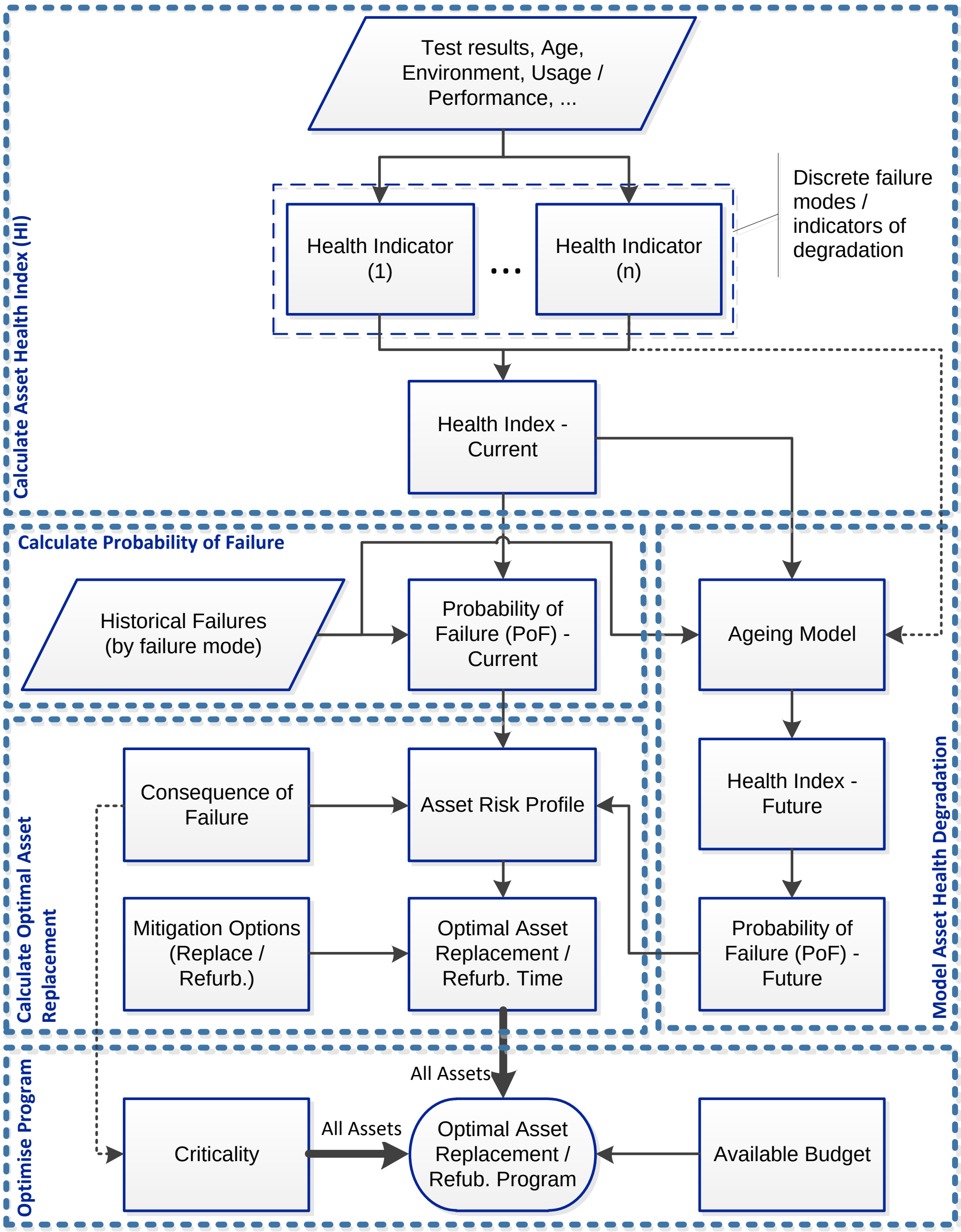


Figure 7: Overview of ARP (CBRM) methodology

Asset Health Index (HI)

The HI is used as a method for describing the condition of an asset based on a variety of indicators of asset health. In the UK, Ofgem requires that utilities report asset health based on a standardised HI (see Table 2) and criticality index (CI) (see Table 3 discussed later). This information enables Ofgem to understand the risk reduction achieved by the various network operators' maintenance and refurbishment programs (i.e. the return on investment).

The definitions provided in Table 2 outline a very subjective classification system. As such, Ofgem have historically allowed network operators to develop their own methodology for assessing and allocating assets within these categories (provided that this method is well documented and justifiable). In doing so it is important that network operators apply their classification system consistently across all types of assets. That is, HI rankings should not have a different meaning for different types of assets. UKPN built on Ofgem's HI definitions to provide an analytical link between asset health and remaining life (or conversely the PoF). These ARP HIs are then mapped to the Ofgem defined HIs for reporting purposes.

Table 2: Ofgem HI rankings and definitions [13]

HI Ranking	Definition
HI1	New or as new
HI2	Good or serviceable condition
HI3	Deterioration requires assessment and monitoring
HI4	Material deterioration, intervention requires consideration
HI5	End of serviceable life, intervention required

The ARP model uses a number of health indicators for each type of asset. These indicators are generally linked to modes of failure for the specific asset class but may be as simple as asset age or location. Each of these health indicators are calculated for a single asset and combined to calculate a single asset health figure (or HI).

Probability of Failure (PoF)

Calculation of asset PoF is vital in assessing the risk profile of an organisation; it is also intrinsically linked to the ARP HI derivation. The ARP model proposes a third-order polynomial relationship between HI and PoF. Where possible, the coefficients of this curve are tuned using historical failure data. Where "good" failure data is not available the model is tuned using past experience and best estimate.

For completeness, the ARP model takes account of the overall PoF; that is the PoF including the likelihood of a non-condition-related fault (e.g. exceptional weather conditions, or third-party damage). However, when assessing investment options, the impact of different types of mitigation on the PoF must be considered (e.g. refurbishment or replacement will not change the risk of failure from lightning strike).

Modelling Future Asset Health ("Ageing Model")

The process of calculating HI and PoF provides a snapshot of risk at a single point in time. To understand how this risk changes, the future health of assets must be estimated. By doing so an organisation can calculate:

- the optimal time for replacement or refurbishment in an asset's lifecycle;
- how the health of its asset portfolio will change over time and hence the organisation's risk exposure; and
- the improvement in risk profile achieved by intervention.

The ARP model utilises the observation that the health of an asset tends to degrade more quickly as it reaches the end of its serviceable life, predicting an exponential decay in health (and therefore HI). The proposed ageing model has two phases:

1. From "as new" to "end of normal life." This phase models the HI over the asset's normal operating life and is predominantly determined by the (present and future) age of the asset. Beyond this point it is expected that the PoF of the asset will rise significantly.
2. Beyond "end of normal life." Once an asset has exceeded its normal operating life the HI is estimated using condition and reliability information to extrapolate the exponential health degradation. In particular it looks at how assets of similar type and operating conditions, have performed and uses this to predict HI deterioration.

This HI ageing model is estimated for each individual asset covered by the ARP model. As a result, the ageing model takes account of the different physical operating environments (e.g. indoor, outdoor, geographical location) and the operating conditions (e.g. loading, load duration) of the asset to fine tune the rate-of-change of the HI. Where possible the ageing curves are cross referenced with historical data to ensure accuracy and validity.

Risk Profile and Optimal Replacement Time

To provide a meaningful and quantifiable measure of risk UKPN uses the widely accepted practice of assigning pound sterling (£) values to the consequence of a failure (CoF). CoF is classified in four key areas: network performance, safety, financial, and environmental. Each asset covered by the ARP model is analysed against these four CoF categories. This provides an understanding of the value lost in the event of a fault or failure of that asset.

The CoF and PoF (calculated from the HI) can then be used to calculate the risk exposure from an asset at a given point in time. This risk can be extrapolated over time using the ageing model. Comparison of this risk profile and the diminishing cost of mitigation allows for the calculation of the optimal replacement time for an asset. In economic terms, the algorithm calculates the point where the marginal cost reduction of mitigation becomes less than the marginal increase in risk that can be mitigated.

Optimising the Program

The final element of the ARP model is to develop an optimised asset replacement and refurbishment plan. As with all engineering challenges, while there may be an ideal asset replacement time, budgeting, time and resourcing constraints limit the work that can be undertaken. Therefore, it is important to understand the criticality of each asset; particularly in comparison to assets of different type. To this end, Ofgem has provided standardised criticality rankings for reporting purposes (see Table 3). However, as for the Ofgem HIs, these are subjective measures that require interpretation by network operators. UKPN has defined relative (i.e. within an asset class) and absolute (i.e. comparing different asset classes) mappings for these critically scores, linking them to quantifiable CoF values.

Table 3: Ofgem criticality rankings and definitions [13]

Criticality Ranking	Definition
C1	Low Criticality
C2	Medium Criticality
C3	High Criticality
C4	Very High Criticality

Using these HI and CI scores Ofgem defines a risk index. This risk index will be used during RIIO-ED1 for utilities to report their proposed and achieved network risk to Ofgem. Organisations that fail to achieve their proposed risk score without suitable justification may be exposed to revenue penalties. Therefore, minimising the risk score by prioritising high risk assets is an ideal way to allocate limited budgets while assuring maximum risk benefit.

5.4.2 Lessons Learned

My experience with ARP has allowed me to gain an understanding of how the model is applied, the benefits of utilising a system to analytically optimise investment in asset replacement and refurbishment, and some of the challenges that the system faces. The development of HIs as a tool for highlighting asset health is not a new concept; however, the benefit of HIs is only truly realised when coupled with the concept of PoF and CoF (or criticality) to quantify the resultant risk to the business.

Each of these calculations (HI, PoF and CoF) are reliant on the availability of “good” data both current (in the case of HI) and historical (in the case of PoF and CoF). Without this data to objectively calibrate and perform calculations there is the need for assumptions, expert experience, or best estimate judgements. Although these are applied with the good intentions, they are likely to subjectively influence the outcome. It is therefore important that organisations share information, particularly in relation to asset failure and indicators of failure (e.g. through forums like EPRI, ENA's NEDeRS, and CIGRÉ). I believe regulators should look to encourage organisations to participate in building relevant libraries of asset failure data. This would be particularly advantageous in Australia, where networks are often subject to different environmental challenges to those of their North American or European counterparts.

From a regulatory perspective, there is significant value in understanding the asset health and resultant risk exposure of organisations. This information allows for industry benchmarking and comparison; however, accomplishing this in a meaningful capacity requires that organisations use similar (if not the same) methodology and classification system. Ofgem's current model for HIs and criticality affords significant scope for interpretation. To resolve this issue Ofgem have requested that DNOs collaborate to achieve greater consistency in the way they calculate asset HIs, and CIs. The method currently favoured as the way forward is to directly link HI and PoF (as is done within UPKN). This then raises an additional challenge that DNOs must define asset failure in the same way. Ultimately DNOs are due to submit their proposal for a common methodology of HI and CI calculation to Ofgem in July 2015. Following this Ofgem will issue a directive on a unified method for calculating HI and CI for assets.

In the Australian regulatory environment, where prudently managing an ageing asset population is a predominant issue, the UK's regulatory model offers a number of advantages. The Australian Energy Regulator (AER) could learn from Ofgem's experience and work toward a similar model, requiring network operators to report against a well-defined set of HI, CI and risk categories. With this information the AER could engage network operators in more robust negotiations regarding expenditure requirements for asset replacement and refurbishment.

Overall I feel that ARP (or CBRM) provides a valuable analysis tool. There is still room for improvement within the calculation of HI, PoF and ageing, but these issues can be resolved over time. In most instances these issues are the result of poor data, something that can be resolved with the benefit of time.

6 Future Works

For my remaining six months with UK Power Networks I will continue working on the transition from PAS55 to ISO55000 as this is planned to run into March 2015. The next stage of this project will focus on closing the gaps that have been identified and working with a small group of consultants to develop an "Asset Management Manual." I will also continue my involvement with:

- the ARP tool – where I will be documenting the distribution transformer model; and
- the DNV project – where I hope to be involved in development of aspects of the tool;

I'm also planning on undertaking a number of short placements within other Asset Management or asset management-related groups to gain an appreciation for some of the challenges that UKPN are facing and how they're managed. In particular, I am planning to work with:

- The Strategy and Regulation team – to gain understanding of the pressures that are being placed on UKPN by Ofgem.
- The Network Design Standards team – looking at work UKPN has undertaken in partnership with the Imperial College of London to develop a load related model of UKPN's network out to 2050. This model allows UKPN to assess the impact of different economic growth scenarios and technological developments on its network. With this model UKPN have been able to estimate future network constraints, augmentations and load related expenditure.

- The Business Transformation project – UKPN is undertaking a significant consolidation of its IT systems into a single business platform. Upon completion, the SAP system being developed for UKPN will encapsulate all core business data. As a major stakeholder in this system, Asset Management is heavily impacted by the change.
- I also hope to visit UKPN's control centre in Ipswich, Suffolk in addition to some of UKPN's electrical substations.

Over the coming weeks I will also be continuing discussions with a number North American and Canadian network operators and will provide the board with notification that I have secured my second placement by the end of January 2015.

Outside of work I have attended events held by CIGRE Central Office (France), the CIGRÉ UK Next Generation Network, and other general interest engineering events (see Section 7). In the coming months I will be attending presentations on the construction and operation of the London Array offshore wind farm and on the development of smart grids among other IET and NGN events.

In my personal endeavours I have spent much of the past three months exploring the south of England. Now that I am well established in the area, I hope to explore more of the UK and further abroad in Europe. I am eagerly awaiting the festive season and, somewhat naively, the possibility of a white Christmas.

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 CIGRÉ Paris Session

During the last week of August I was able to attend the CIGRÉ Paris Session held at Palais de Congrés in Paris, France[12]. CIGRÉ, the International Council on Large Electric Systems (or in French: Conseil International des Grands Réseaux Électriques), was established in 1921 in Paris, France as a forum for sharing information and leading practices for the advancement of the power industry internationally. While CIGRÉ has grown and diversified over the years, the biannual pilgrimage to Paris remains the flagship event of CIGRÉ.

With more than 3,000 delegates from around the world in attendance, Paris Session does not take the format of a standard conference. While there are a number of "traditional" presentations, there are three core event types that make up the majority of the schedule of Paris Session: study committee sessions, poster sessions, and exhibition stalls. Study committee and poster sessions are organised by area of speciality (referred to within CIGRÉ as a study committee). In addition to this, there were in excess of 100 invite-only meetings for the various study committees and working groups[13]. These sessions focused on specific areas of interest and their related challenges.

7.1.1 Lessons Learned

Paris Session proved to be a valuable professional and personal experience. After attending a number of the Study Committee, Poster, and Working Group sessions it was evident the sheer level of diversity and expertise that was present. While my learnings from Paris Session were significant, I found the keynote speeches and workshops particularly valuable as they discussed topical issues faced by power networks around the world. From these presentations the common focus for developed countries centred on: the usage of High Voltage Direct Current (HVDC) transmission lines to transmit large amounts of power long distances (particularly within Europe and North America), the role of gas in affordable low carbon emission electricity generation, the impact of intermittent

[12] My attendance at this event was thanks to the support of the CIGRÉ Australian National Committee (ANC)
[13] For more information on the study committees and working groups of CIGRÉ see http://www.cigre.org/Technical-activities/Study-Committees-Working-Groups

renewable generation, and the requirement for viable large-scale energy storage. Given the relevance of renewable generation and changing energy electricity environment within Australia I have chosen to discuss the presentations relating to this topic further[14].

Klaus Kleinekorte, Amprion GmbH, Germany discussed challenges that the German electricity network and market are facing as a result of significant renewable (wind and solar) generation penetration. Klaus reported that in some instances the percentage of demand supplied by renewable generation had been as high as 67% or as low as 0.4%. The increase in renewable generation capacity, coupled with generous government incentives and the requirement to prioritise usage of renewable generation has had a significant impact on the German energy market. It has placed downward pressure on the price of electricity (due to an excess of generation capacity), challenging the economic viability of expensive (but dispatchable) thermal generation. While this is often seen as a "green" outcome, dispatchable generation is vital to maintain the stability of the network. Interestingly, Klaus also discussed events whereby an excess in generation had resulted in negative electricity spot prices. (More points of interest from Klaus Kleinkorte's presentation are available below).

Michael Heyek, President US National Committee of CIGRÉ, USA conceived ways in which the electricity network (particularly within the USA) might change in the coming years. Core to his vision of the future network were: gas generation becoming the next major thermal generation (surpassing coal generation), the requirement for seamless coordination of micro-grids with the wider network, the role of technology and energy storage as an enabler to this development, and the need to change pricing signals for customers. Interestingly, Michael's vision was not in alignment with popular concerns that the development of micro-grids may see transmission (and to a lesser extent distribution) networks becoming irrelevant; rather he saw transmission grids as a necessary enabler for a robust market environment. (More points of interest from Michael Heyek's presentation are available below).

The keynote speeches and workshops also reinforced the diverse range of challenges between developed and developing countries. Developing countries within Africa are working to increase network interconnection and remote electrification while working to improve network resilience and stability with limited resources. Alternatively, developed countries are seeing the large-scale integration of new technologies (e.g. electric vehicles, renewable generation) that are impacting the performance and stability of well-established networks. Both instances highlight the need for electricity networks to be more adaptable and vigilant of customer requirements and expectations now than ever before.

Presentation: *Power System Stress Due to Massive Renewable Installation* (Klaus Kleinekorte, Amprion GmbH, Germany) [14]

Introduction:

- Germany's energy:
    - 2020 – 35% of generation from renewables.
    - 2030 – 50% of generation from renewables and 25GW off shore.
    - 2050 – 80% CO_2 reduction below 1990 levels.

Renewable generation issues:

- German regulators require that renewable generation has priority export to the grid. This, coupled with the intermittent and uncontrollable nature of renewable generation, is creating issues in the German power network and electricity market.
- The structure of renewable generation payments means that the transmission network operator (TNO) indirectly absorbs the cost of renewable generation.

[14] Summaries of the various study committee meetings are publicly available on the Paris Session 2014 website (http://www.cigre.org/Events/Session/Session-2014). Presentation slides from the keynote speeches and other accompanying material are made available through the CIGRÉ website for registered attendees of Paris Session,

- Majority of Germany's wind generation is in the north. However, a large portion of usage (e.g. industrial load) is based in the south. Solar Generation is heavily focused in the south.
- Renewable generation is (at times) supplying large portions of energy demand. It has been as high as 67% or as low as 0.4% of the total demand.
- This has led to significant reverse power flow through the network. It was stated that high concentrations of solar generation have resulted in reverse power flow to a transmission level.

Market issues:

- Price of electricity has been decreasing as a result of the requirement to sell renewable generation and significant subsidies for renewable generation (making it cheap to install). As a result of this decreasing cost, thermal plants are no longer financially viable. The result – that renewable generation has distorted the market to the extent that there are instances when the spot price of electricity is negative (because of the surplus of renewable generation).
- Concern that renewable generation will continue to distort the market such that thermal (and dispatchable) generation will no longer be viable, creating a possible shortage when the renewable generation is not available. They need storage to accommodate this transition; however, storage is currently not economically viable.
- If this issue is not dealt with it could create a significant issue in future.

Presentation: *Game Changing Technologies: The Unprecedented Change in the Resource Mix* (Michael Heyeck, President US National Committee of CIGRÉ, USA) [15]

- Rooftop and Pole-top solar PV is growing at a faster rate than wind generation.
- Energy usage is decreasing on the whole, mainly through improvements in energy efficiency; however, we may see this change with new technologies (e.g. electric vehicles).
- One of the major issues is the pricing model for electricity (i.e. charging by kWh). This pricing does not reflect the congestion of the power grid. There is a need for time of use tariffs.
- Prediction that the grid of tomorrow will be a variety of distributed energy resources, with the "game changer" being the development of viable energy storage.
- We also need to look for opportunities in industry to transition processes that are driven by other energy sources to electricity. This will assist in achieving better utilisation of the network.
- Some people are predicting that transmission will not be required; Michael suggested that we will still need the transmission to ensure a robust market. The main change will be the digitisation of the power grid.

7.2 Culham Centre for Fusion Energy (CCFE) Site Visit

In late-September I visited the Culham Centre for Fusion Energy (CCFE) in Abingdon as a part of the CIGRÉ UK Next Generation Network (CIGRÉ's young member initiative). This site visit included:

- a presentation by Chris Warrick (Communications Manager, CCFE);
- a presentation by Steve Shaw (Electrical Engineer, CCFE);
- a tour of the Joint European Torus (JET) and
- a tour of the Mega-Amp Spherical Tokamak (MAST).

This section provides an overview of: fusion energy, basic principles, research at CCFE, the electrical systems used to power the CCFE experiments, and my lessons learned.

7.2.1 Basics on Fusion

Nuclear fusion is a process that occurs in stars throughout the universe (including our Sun) and is responsible for generating heat and light. The allure of harnessing nuclear fusion as a source of energy is largely due to its high energy densities and low environmental impact. In particular, some of the key advantages of nuclear fusion include [16]:

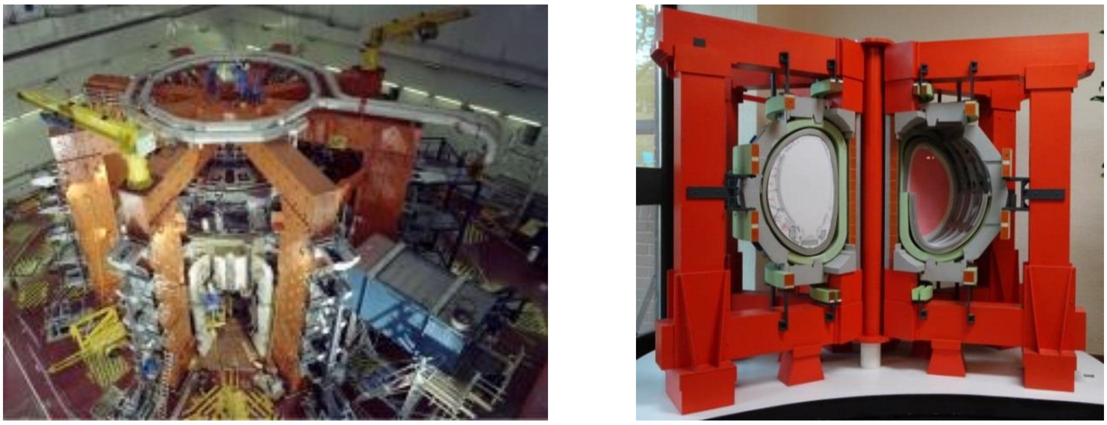
- that fusion does not produce large amounts of radioactive waste[15], unlike the U_{235} (uranium-235)-based fission (utilised in existing nuclear power plants);
- that there is no possibility of a runaway reaction (also known as meltdown), as the heat required to initiate and sustain the reaction will quickly dissipate in an uncontrolled environment; and
- that the proposed deuterium-tritium reaction produces no direct greenhouse gas emissions.

It is worth noting that the specific isotopes of hydrogen proposed for use in electricity generation are deuterium and tritium, the second (^{2}H) and third isotopes of hydrogen (^{3}H). While deuterium is readily available in the water, tritium, the radioactive component of the fusion reaction, is extremely rare. To achieve fusion on a commercial scale, tritium would be produced as a part of the fusion process by bombarding lithium-6 (^{6}Li) with nuclei radiated from the fusion reaction [17].

For more information on fusion the CCFE's website (http://www.ccfe.ac.uk/introduction.aspx).

7.2.2 The Tokamak

The CCFE has two tokamaks on site, the Joint-European Torus (JET) (see Figure 8), and the Mega-Amp Spherical Tokamak (MAST). JET, as the name suggests, is funded by a number of European countries, while MAST is funded entirely by the UK.



(a) ***(b)***

Figure 8: (a) The JET [18]; and (b) A model of the JET

Interestingly, neither tokamak is focused on capturing the energy produced by fusion to produce electric energy; instead they are being utilised to experiment with and refine the fusion process.

The fundamental fusion process of the tokamak operates using two electro-magnetic circuits:

1. The toroid magnets situated around the sphere of the tokamak and are used to create a circulating magnetic field. This field confines the path of plasma to a torus shape, ensuring that the plasma does not collide with the walls of the tokamak and lose its heat.
2. The ohmic heating magnet, which runs through the centre of the tokamak, generates a magnetic field that strikes and heats the plasma to 100 million°C [18], allowing fusion to occur.

Powering this energy intensive process is a significant challenge, particularly when considering that the supply for this system was designed and built approximately 30 years ago.

7.2.3 Electrical Supply

The electrical supply for the JET is a complex combination of AC and DC systems with the primary point of connection 400kV AC to the National Grid (UK's transmission network operator) network. The

[15] This statement requires some clarification. Depending on the fused elements, nuclear fusion may actually produce radioactive materials in the surrounding environment.

CCFE has an agreement with National Grid for a 575MW pulsed connection. However, this connection alone does not provide enough power for the JET. Additional power is supplied via two 775 tonne, 400MW flywheels [19]. The toroidal and ohmic heating magnets are powered by DC circuits, therefore a large portion of the power supply for JET (and the lower powered MAST) consists of high power rectification devices. Points of interest relating the electrical supply system include:

- The connection to National Grid is used in a pulsed arrangement. If National Grid are concerned about the impact of this pulsing on network performance they reserve the right to stop CCFE's experiments.
- The peak current, drawn at the height of JET tests, is 76kA. This is supplied from all three available energy sources: the connection with National Grid, and the two flywheel units.
- Duration of testing within JET is limited by the I^2R heating of the electromagnet coils which start to overheat. In future designs this will be resolved by cryogenically cooling the electromagnet.

7.2.4 Lessons Learned

The presentations and tour of both facilities made for an interesting and enlightening site visit. From this tour I had a number of takeaway points:

- The highest energy gain of the JET (output fusion energy divided by input heating energy) is less than one. The widely accepted method for increasing this gain is to increase the volume of the tokamak, in turn increasing the mass of plasma gas resulting in a greater heating capacity. This requirement is reflected in the development of the International Thermonuclear Experimental Reactor (ITER)[16], which is 10 times larger (by volume) than the JET.
- At a cost of approximately €14 billion and a (tentative) operating date of 2020, ITER is the next major development for fusion experimentation. It is hoped that ITER will have an energy gain of approx. 10. (Note: this figure refers to fusion energy, not electrical energy).
- The first commercial-scale tokamak for electricity generation, known as DEMO, is planned for completion by 2050, but there is some debate over this timeline. To achieve the fusion durations required for commercial generation, DEMO will be larger than ITER.
- Although the basic principles are understood, very little research has been done on the capture of fusion energy and transforming that into electrical energy. This conversion from fusion to electrical energy will undoubtedly add inefficiencies and erode the energy gain figures provided.

Overall, nuclear fusion for use in electricity generation seemed to be maturing as a technology. It appears that there is still many decades of research required before the realisation of a viable reactor, the likes of which is proposed for DEMO. Given the cost intensive nature of this research, I imagine research organisations (such as ITER and the proposed DEMO) will face significant challenges securing funding in future. However, it is the tantalising prospect of unlocking nuclear fusion as a viable energy source, with the possibility of replacing less environmentally friendly forms of generation that will likely ensure research in this area continues.

In an Australian context, long held safety and environmental concerns relating to nuclear fusion energy, coupled with the availability of cheap coal and natural gas has impeded the development of nuclear power plants. If nuclear fusion were to develop as a viable source of electricity it will not have the same safety and environmental concerns of nuclear fission, in turn offering environmental benefits over coal and natural gas. The only remaining challenge is the affordability of a commercially viable nuclear fusion generator. If this is realised, nuclear fusion could play a big part in energy mix of Australia in the 22nd century.

[16] ITER is currently under construction in Cadarache, France

8 Bibliography

[1] Australian Government: Department of Industry, “The fact sheet on electricity prices,” February 2013. [Online]. Available: http://www.industry.gov.au/Energy/EnergyMarkets/Documents/ELECTRICITY-PRICES-FACTSHEET.pdf. [Accessed 12 October 2014].

[2] UK Power Networks, “Annual Review 2013,” June 2014. [Online]. Available: http://www.ukpowernetworks.co.uk/internet/en/about-us/documents/UKPN%20Annual%20Review%202013%20web.pdf. [Accessed 12 October 2014].

[3] UK Power Networks, “Business Plan (2015 to 2023): Executive Summary,” March 2014. [Online]. Available: http://library.ukpowernetworks.co.uk/library/en/RIIO/Main_Business_Plan_Documents_and_Annexes/UKPN_Overall_Executive_Summary.pdf. [Accessed 12 October 2014].

[4] Office of Gas and Electricity Markets (Ofgem), “Price controls explained,” March 2013. [Online]. Available: https://www.ofgem.gov.uk/ofgem-publications/64003/pricecontrolexplainedmarch13web.pdf. [Accessed 12 October 2014].

[5] Office of Gas and Electricity Markets (Ofgem), “BSI-PAS 55 Certification and the Stakeholder Working Group,” 5 April 2006. [Online]. Available: https://www.ofgem.gov.uk/ofgem-publications/52172/13523-0167.pdf. [Accessed 12 October 2014].

[6] British Standards Institution, PAS55-1: Specification for the optimised management of physical assets, London: British Standards Institution, 2008.

[7] British Standards Institution, BS ISO 55000 series, January: 31, 2014.

[8] British Standards Institution, “Moving from PAS55 to BS ISO55001: The new international standard for asset management,” 2014. [Online]. Available: http://www.assetmanagementstandards.com/resources/Moving+from+PAS+55.pdf. [Accessed 16 October 2014].

[9] J. Woodhouse, “ISO55000 Introduction,” December 2013. [Online]. Available: http://www.assetmanagementstandards.com/resources/ISO55000+introduction+v1.1.pdf. [Accessed 28 October 2014].

[10] J. Rowley, “The wisdom hierarchy: representations of the DIKW hierarchy,” *Journal of Information Science,* vol. 33, no. 2, pp. 163-180, 2007.

[11] UK Power Networks, “Distribution Network Visibility: LCN Fund Tier 1 Close Down Report,” December 2013. [Online]. Available: http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-1-projects/distribution-network-visibility/Project-Documents/DNV+CDR+Version+3.0+270214.pdf. [Accessed 3 November 2014].

[12] UK Power Networks, “Innovation: Distribution Network Visibility,” 2013. [Online]. Available: http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-1-projects/distribution-network-visibility/. [Accessed 30 October 2014].

[13] Office of Gas and Electricity Markets (Ofgem), “Strategy decision for the RIIO-ED1 electricity distribution price control: Reliability and Safety,” 4 March 2013. [Online]. Available: https://www.ofgem.gov.uk/ofgem-publications/47073/riioed1decreliabilitysafety.pdf. [Accessed 11 November 2014].

[14] K. Kleinekorte, “Power system stress due to massive renewable installation,” in *CIGRÉ Paris Session 2014*, Paris, 2014.

[15] M. Heyeck, “Grid Transformation in the United States of America,” in *CIGRÉ Paris Session 2014* , Paris, 2014.

[16] Culham Centre for Fusion Energy (CCFE), “Fusion Energy: Introduction,” 2012. [Online]. Available: http://www.ccfe.ac.uk/introduction.aspx. [Accessed 4 October 2014].

[17] International Experimental Thermonuclear Reactor (ITER) Organisatoin, “Fusion Fuels,” 2014. [Online]. Available: https://www.iter.org/sci/fusionfuels. [Accessed 4 October 2014].

[18] Culham Centre for Fusion Energy (CCFE), “The Tokamak,” 2012. [Online]. Available: http://www.ccfe.ac.uk/Tokamak.aspx. [Accessed 4 October 2014].

[19] A. Parkin, “Power supply and flywheels,” [Online]. Available: http://www.efda.org/fusion/jet-tech/jet%E2%80%99s-flywheels/. [Accessed 4 October 2014].

[20] Department of Energy & Climate Change, “Domestic electricity prices in the IEA (QEP 5.5.1),” 25 September 2014. [Online]. Available: https://www.gov.uk/government/statistical-data-sets/international-domestic-energy-prices. [Accessed 30 November 2014].

[21] Office of Gas and Electricity Markets (Ofgem), “(Updated) Household energy bills explained,” February 2013. [Online]. Available: https://www.ofgem.gov.uk/ofgem-publications/64006/householdenergybillsexplainedudjuly2013web.pdf. [Accessed 30 November 2014].