Project FALCON

Final Report

September 2015

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FALCON

Contents

Executive Summary

Project FALCON was a Low Carbon Network Fund initiative started in 2012 that set about to test the following:

“The general assertion being that the cost and limited flexibility of traditional approaches to 11kV network reinforcement threaten to constrain the uptake of low carbon technologies. “

In order to really test this assertion FALCON had a number of dependent and standalone workstreams and this final report is a collation of several reports pertaining to those workstreams. Not all information is contained within this document, as it is a general summary of the various workstreams but the reader will be directed throughout to the relevant location for more analysis and information.

In summary the project tested a series of engineering techniques and the high level findings were that the energy storage trials delivered strong results, despite still being a high cost to deploy; meshed networks delivered load changes but not on the more heavily loaded source breaker during peak; the Automated Load Transfer (ALT) algorithms did have a beneficial impact on losses and overhead minimum voltages whilst Dynamic Asset Rating (DAR) showed that real time dynamic ratings is hugely variable despite the modelling; and

The Commercial Trials were deemed widely successful; generating significant learning about how DSR could be utilised by a DNO. It was discovered that whilst the capacity used on the 11kV trial network was indeed useful, there were more significant benefits to be explored on higher voltage networks.

For Load Estimation, in general the analysis highlighted the need to assess and, if validated, improve the quality of customer data and connectivity data which can be a factor in estimates that are not representative of the real loads.

The Scenario Investment Model workstream developed and used a complex but effective planning tool for the 11kV network. The team successfully ran a number of simulation experiments over a range of timescales for various sections of the network and was able to draw a number of conclusions about the evolution of the network under a range of future demand scenarios as modelled by the load estimation workstream. A full description of the tool and an analysis of the results is available on the WPD Innovation website.

The FALCON Telco’s Network was found to be stable once a number of issues were remedied, however it is currently perceived to be too high cost when compared against other technologies. The intention now is to try to extend the learning from FALCON into a new project for 2016 whereby comparing other technologies will determine the optimal way forward for a DNO.

Knowledge Capture and Dissemination was extremely successful overall and indeed the learnings from FALCON have informed subsequent competition bids. More importantly though the volume and quality of learning has been extremely powerful for use internally when reflecting upon transition into BaU as policies or future projects. The most powerful evidence of this has been how the data collection activities within FALCON have regularly been used off project within BaU and one of the next challenges for future work is to see how this can be maintained and even extended beyond Milton Keynes.

Throughout the project FALCON has met a series of challenging milestones and Successful Delivery Reward Criteria. Wherever possible we have highlighted links to various reports that have been published during the lifecycle.

This report contains elements of the detailed reports that form part of the overall close down activity for FALCON. Wherever possible we have tried not to reinvent things, we have therefore provided extensive links back to more detailed documentation so that the reader can delve into the detail as required rather than one over large document. We think this works well, but would be pleased to receive any feedback to wpdinnovation@westernpower.co.uk.

Other important documents contained within the suite are :

A glossary which can be found here:

http://www.westernpowerinnovation.co.uk/Document-library/

SDRC documents can be found here:

Project FALCON Load Estimation Report – April 2013

http://westernpowerinnovation.co.uk/Document-library/2013/Project-Falcon-LoadDataFindings.aspx

SDRC 3 Content- Hotspot Map Update –September 2013

http://westernpowerinnovation.co.uk/Document-library/2014/5-Hotspot-Map-SDRC-3-Report-v1.aspx

Summer 2014 Interim Commercial Trials Report- July 2014

http://westernpowerinnovation.co.uk/Document-library/2014/FALCON-Commercial-Trials-Season-1-Winter-2013-14-v.aspx

SDRC 4 Summary –October 2014

http://westernpowerinnovation.co.uk/Document-library/2014/SDRC4-Report-October-2014.aspx

SDRC 4 Content - Energy Model Comparison of Estimates to Monitored values–Oct 2014 http://westernpowerinnovation.co.uk/Document-library/2014/FALCON-SDRC-4-output-Energy-Model-Comparision-of-E.aspx

SDRC 4 Content- energy model scenarios consultation with other DNO's October 2014

http://westernpowerinnovation.co.uk/Document-library/2014/FALCON-SDRC-4-Output-Falcon-Scenarios-Report-v2-0.aspx

SDRC 5 on FALCON Trials Learning and SIM Summary December 2014

http://westernpowerinnovation.co.uk/Document-library/2014/SDRC-Report-Initial-FALCON-trials-learning-Dec-201.aspx

SDRC 5 Detailed Report December 2014

http://westernpowerinnovation.co.uk/Document-library/2014/SDRC5-Report-December-2014.aspx

SDRC 5 Battery Functional Specification December 2014

http://westernpowerinnovation.co.uk/Document-library/2014/Technique-4-Functional-Spec-v1-issued.aspx

SDRC 6 on Commercial Trials December 2014

http://westernpowerinnovation.co.uk/Document-library/2014/SDRC6-Report-December-2014.aspx

SECTION 1

Project Scope & Objectives

The scope of FALCON was considerable with a number of dependent and standalone workstreams as follows:

- Engineering Trials
- Commercial Trials
- Scenario Investment Model
- Telecommunications
- Knowledge Capture and Dissemination
- Load Estimation

In addition there was the need to also measure any potential benefits that could be realised from the operation of the trials in business as usual as well as considerable modelling and analysis.

Within the bid document the scope of the project was predicated on the assumption that the cost and limited flexibility of traditional approaches to 11kV network reinforcement threaten to constrain the uptake of low carbon technologies.

We stated that FALCON sought to address this through trialling of a Method that comprises a Scenario Investment Model (SIM) linked to a network trials area. Project FALCON trialled four engineering and two commercial alternatives to conventional reinforcement. The trials area sought to prove the practically of these techniques.

The SIM was intended to identify network constraints under multiple future network load scenarios and determine the most cost-effective and timely combination of techniques to resolve them. The trial area comprised six primary substations located on a mix of rural and urban networks representative of 90% of the national 11kV network.

The objectives of FALCON were closely aligned with those of the UK Low Carbon Transition Plan and ED1. In addition to enabling the uptake of low carbon technologies, FALCON sought to determine to viability of delivering faster and cheaper 11kV connections and reduced DUoS charge increases for all.

It also sought to generate learning applicable to all DNOs, shared through established LCNF dissemination channels. In addition to a net financial benefit of £1.2m from the four year project, we estimated that a national rollout of FALCON could realise a £660m financial benefit over 20 years and will save over 680 ktonnes of CO2 by 2050 (accounting for an additional £36m of benefits).

Within this report we have dedicated a section to discussion on the benefits, where applicable, of the technologies used. We have also discussed our approach to benefits throughout.

SECTION 2

Engineering Trials

2.1 Executive Summary

The engineering trials within the FALCON project demonstrated and explored four innovative techniques aimed at relieving technical constraints on an 11kV network. The trialled techniques were dynamic asset rating, automatic load transfer, meshed network and energy storage. These techniques are alternatives to conventional reinforcement, the conventional engineering remedy to network constraints.

Each technique trial was composed of: specification and selection of equipment (including monitoring); installation and commissioning; operation of assets and monitoring during trial operations; pre- and post-operation modelling and validation; and impact assessment. In doing this, the trials informed the FALCON Scenario Investment Model (SIM) about how such techniques could be modelled. Networks in the Milton Keynes area were selected as: an area with strong low carbon ambitions; providing examples of typical 11kV infrastructure; but not actually under constraint. This absence of constraint provided time to investigate the techniques appropriately whilst, minimising potential impacts on customers.

Trials were successfully implemented for all four project techniques. Data was initially gathered in November 2013, and extended through until June 2015. Valuable learning was identified and accrued from the design and installation phase through to final analysis and reporting. Recommendations have been established associated with each of the techniques. The following paragraphs outline the experience from each technique trial.

Dynamic Asset Rating of 11kV overhead lines (OHL), 33/11kV transformers, 11kV/400V transformers and 33kV and 11kV cables sections were undertaken, though it should be noted that by design none of the assets in the trial were approaching thermal limits. For all the asset types (e.g. OHL, cables, and transformers) periods of time were found where the real-time dynamic ratings [1]were above the applicable static rating, and there were periods when the dynamic ratings were below static ratings. For example, for a trialled 11kV OHL, all months except September saw the mean dynamic rating for the month being greater than the applicable static rating; however, the minimum real time values were lower than the static rating for the majority of months. In addition, extensions to the technique were developed in the area of estimating likely future dynamic ratings (based on forecast weather). From the DAR work of this project it is recommended that further work on primary transformers could be taken forward, and that this should initially focus on a candidate primary transformer to trial actual solution provision (to an asset nearing capacity) and demonstrate in-service benefit delivery

Automatic load transfer trials on two portions of networks (one characterised as rural with predominately OHL, and one as urban with cables) suggested that this technique may be able to remove capacity constraints, though this is dependent on specific network

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[1] a rating calculated at a point in time that depends on the current thermal state of the asset, and the ambient environmental condition at the time of calculation

circumstances. Of more immediate benefit, the technique trials suggest a potential widespread reduction in network losses may be possible through a one-off review of normal open point locations. It is recommended that a candidate portion of network could be assessed using this technique to trial actual standardised provision, where network is currently approaching/is at limits.

The mesh implementation and trialling under FALCON was restricted to simpler configurations due to new learning from the FALCON Telecoms Workstream which showed that the speed of telecoms signalling can be a limiting factor for complex mesh deployment. Consequently the commissioning and testing scope consisted of a two feeder mesh with two zones of protection. The completed testing showed that meshing does not necessarily tend to equalise load across feeders, because current re-distribution is a function of feeder impedance and load location. For the trial circuit, no improvement in useful capacity headroom was achieved. However, the potential to affect this key issue is predictable and network specific. Based upon the trial findings, it is not recommended that meshing will provide a widespread means of mitigating potential changes in network use as considered by FALCON. However, it is recommended that the installed infrastructure is retained to potentially test continuing work on high-speed performance of modern communications networks.

The energy storage trial installed systems at five Distribution substation locations on one 11kV feeder, and provided valuable learning on site selection and installation challenges. Operational performance demonstrated: effective peak-shaving at both individual substation and feeder level; limited voltage management through reactive power output; and the potential to satisfactorily react to grid frequency (one example of an ancillary service). The trial provided valuable insight into the operational capabilities of such devices, and their wider impact on the network. It is recommended that technology tracking is undertaken in this field, principally against the potential for the technique's use by connected customers, possibly seeking to maximise energy through a connection point, whilst limiting the authorised capacity of the connection.

The detailed reports of the Engineering Trials can be found here:

http://www.westernpowerinnovation.co.uk/Document-library/

2.2 Overview of FALCON Engineering Techniques

2.2.1 Overview of techniques

In the past, network operators have mainly used conventional reinforcement to deal with network constraints. Conventional reinforcement is the replacement of an asset (the loading of which has or is imminently expected to exceed the nominal capacity), with an asset having greater capacity. This approach can lead to assets that have significant spare capacity for the majority of time throughout a given year, but crucially does ensure that the system adequately supports annual peak demands. Consequentially, this approach can to some extent be costly, disruptive (during construction) and inefficient. In Project FALCON, WPD have trialled a number of engineering techniques to assess their potential on the 11kV network as alternatives to conventional reinforcement. The trial techniques are:

Dynamic Asset Ratings (DAR)
Traditionally overhead lines (OHL), transformers and cables have been assigned capacity ratings intended to ensure operation within safe operating limits, and allow assets to achieve nominal service life. These ratings may be fixed for specific periods of time (e.g. summer and winter ratings of cables), or may relate to a load that has a daily cyclic characteristic (e.g. transformer and cables). However, these ratings essentially do not take the current/present environmental conditions into account, nor do they take into account the current/present thermal state of the asset. In this respect, the ratings are regarded as “static” – not responsive to the current thermal or environmental conditions of the asset. These “static” ratings make assumptions about prevailing environmental conditions (air temperature, wind speed and direction etc.) and set a limit on electrical current passing through the asset such that safety and service life of the assets are maintained.

DAR seeks to allow operation of these assets beyond the static limits, through dynamic assessment of the asset’s actual thermal state (derived from preceding operating circumstances), and the present environmental factors. Whilst seeking to increase capacity, this technique can also identify periods where the dynamic rating is calculated as less than the static rating, thereby potentially reducing the asset’s rating under some circumstances. The dynamic rating is often referred to as ‘ampacity’ – the maximum current that can pass through an asset before the temperature limits are reached.

This technique seeks to properly re-assess the capacity of assets during peak usage periods to alleviate constraints, whilst maintaining safety and managing impact on asset life. DAR can also be used to constrain flexible use of assets (e.g. generation) when environmental/load conditions are not favourable.

Automatic load transfer (ALT)
A very large number of circuits at 11kV on WPD distribution networks are run in an ‘open ring’ configuration. On these circuits, feeders from the same or adjacent primary substations are electrically connected together at the feeder extremity via a switching device that is normally in the open position. These feeder inter-connection points are referred to as Normal Open Points (NOPs). All loads on such circuits are ordinarily associated and fed from a specified feeder/Primary Substation. It is possible to close these normal open points and create an open point elsewhere on the network (maintaining the open ring nature of the network), and change the feeder/primary substation that a load (or number of loads) are fed from. Routinely this is done under maintenance or fault circumstances.

The positions of NOPs on a mature portion of network have been established for a variety of reasons, including limiting load/customer numbers on a single feeder, and allowing immediate access for switching purposes. In many instances, these NOPs have been in place for lengthy periods of time (years). As such, their position may no longer be optimal with respect to losses, voltage, and feeder capacity headroom, particularly where incremental growth in load on a network (within authorised supply capacities) has occurred.

On the 11kV network, ALT is the process of changing the state of switching devices on the network to shift the location of the open points, and cause an improvement in the network's performance. Deliberately changing the open point location, and consequentially what loads are supplied from which substations, affects the key network parameters of losses, voltage, and capacity headroom. It can also impact the number of customers affected by a fault.

This technique seeks to change power flow on the network through alternative open point locations, and consequentially increase capacity headroom on identified feeders for load or generation, and also to improve other operational parameters (losses, and voltage). It should be noted that overall, this technique moves load from a potentially constrained feeder, to an adjacent feeder that has sufficient capacity.

Meshed (interconnected) 11kV network
An alternative approach to improving network performance through modification of open point locations is to simply close NOPs, establish inter-connect portions of network and move away from pre-existing open-ring configurations.

This approach fundamentally allows the load on each feeder in a meshed circuit to deviate according to the routine variations in the connected load, without the need for pre-existing analysis and changes to switch states.

However, simply closing NOPs exposes more connected customers to supply interruption following a network fault. Therefore, under this technique, closure of open points for long term operation is accompanied by the installation of along-the-feeder fault sensing and interruption equipment (protection relays and circuit breakers). This restores the limitation of fault impact on customers that the NOPs provided and, through the installation of more protection relays/circuit breakers, connected customers can be provided with a lower probability of interruption. However, the installation of such equipment introduces additional cost and complexity.

This technique also seeks to change power flow on the network, and alleviate constraints by closing NOPs. In concert with closing NOPs, the technique provides additional protection/circuit breakers to maintain/improve connected customer resilience to faults.

Battery-backed Energy Storage (ES)
Typically high load half-hour periods (half-hour peak load over 90% of the annual peak load) occur for less than 1% of time throughout the year. These high load half-hours are spread across around 10% (36) of the days in a year, normally over the winter period. It is this very small proportion of total number of time periods that traditionally identify a circuit as having load approaching capacity. Energy storage is an alternative technique for addressing this situation.

(Electrical) Energy Storage systems mostly use batteries to store energy during time periods of low demand, and discharge that energy during periods of high demand, reducing the peak amount of power being drawn from the wider network. In effect, energy storage systems shift the time at which some of the demand is presented to the network, moving it from a period of high overall demand (where the network may be out of capacity), to a period of lower demand (where the demand can be accommodated).

Energy Storage systems may provide additional functionality for example: import/export of reactive power to improve voltage; and import/export real power, according to measured grid frequency, potentially providing a commercial ancillary (grid) service.

This technique primarily seeks to delay or remove the need for conventional network reinforcement by time-shifting demand; whilst also potentially improving other network parameters and providing (commercial) ancillary services.

2.2.2 Summary of potential technique impacts

The techniques seek improvement in a range of technical network parameters. This includes:

- Thermal/feeder capacity, network voltage, fault level, losses, and power quality; and
- Customer performance; enablement of distributed generation; and grid/network services.

2.3 Overview of technique implementation and trials

The broad objectives of trialling the techniques were:

- to understand the implementation of the techniques;
- to understand operational capability of the techniques;
- to attempt to replicate the asset behaviour offline through modelling; and
- to use the models to inform the SIM and explore the operation of the asset under conditions not seen on the trial (e.g. heavy loading).

Each technique trial was composed of: equipment installation and commissioning; monitoring; operation of assets; pre- and post-operation modelling and validation; and impact assessment. The following sections provide an overview of the implementation of each technique trial.

2.3.1 Dynamic Asset Rating Trial

The installed equipment comprised of two categories: equipment necessary to provide data that was then used to model the assets (e.g. Alstom P341 relays and associated input parameter instruments, plus offline models); and equipment used to measure the key resultant temperatures of the assets to allow the thermal models to be validated. The dynamic asset rating trials installed equipment on:

- Three 11kV overhead lines (OHL) coming out of Newport Pagnell Primary substation;
- Two 33/11kV transformers at Marlborough Street Primary Substation;

- Sixteen 11kV/400V distribution transformers in the Milton Keynes area; and
- Three sections of cables: two 33kV cables between Bradwell Abbey and Newport Pagnell, and one 11kV cable (part of Burtons Redmoor feeder (11) from Bletchley 11kV switchboard).

The monitoring (schematic illustrated in Figure 1) principally consisted of:

- Data-logging of values from the P341 relays (this included input values such as electrical current, a range of prevailing ambient conditions, and relay-calculated DAR parameters) to Matrikon OPC[2] software and storage;
- data-logging of values from asset specific temperatures probes (both thermocouples and resistance thermometers plus Tollgrade Lighthouse MV OHL sensors – see picture in figure 1) providing feedback of the actual thermal state of assets;
- data-logging of Distribution transformer currents via Gridkey (LV) substation monitoring sets; and
- transmission of data over the FALCON trial communications network;
- Conditioning of collated data for subsequent analysis.

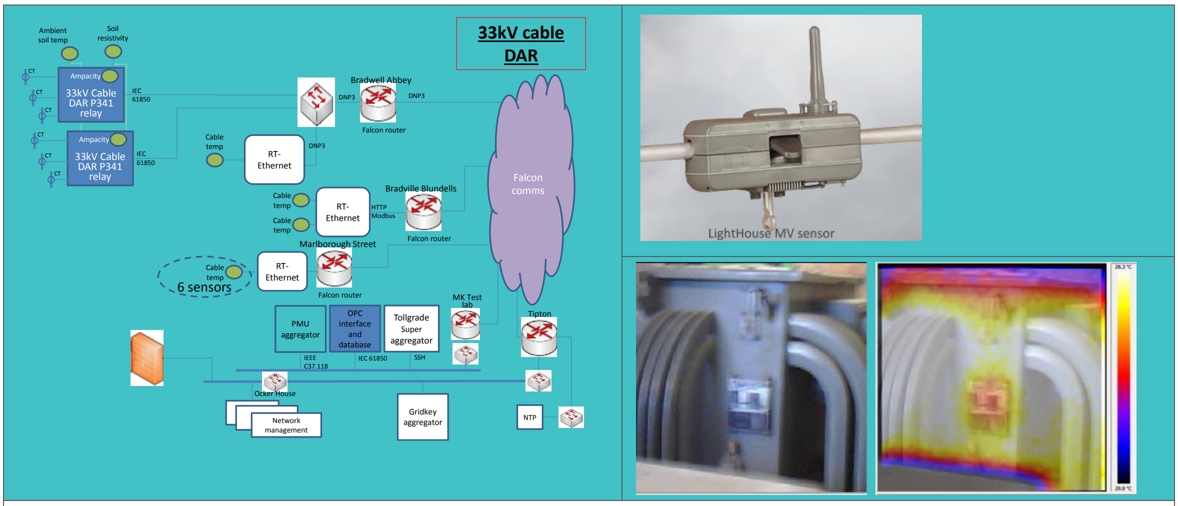

Figure 1: Selected images characterising the DAR trial and associated equipment.

Thermal modelling of assets and validation of modelling results against measured asset temperatures was carried out for the installed Alstom P341 relays and also in offline models. The offline models were established to: validate the relay outputs (for which source code was not available); and to provide a platform for more extensive analysis than the relays provided, including the extension into the area of forecasting future ampacities. Figure 1 above includes a thermal image of a distribution transformer, such imaging was used to cross check the results of thermal modelling.

Operation of assets within the trials included both passive and active operations. The passive monitoring covered the normal service operation of the assets over a full range of ambient conditions that a 12 month period presented. The active operation involved

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[2] Object linking and embedding for Process Control

changes to service duty that verified thermal models outside of normal operating levels (e.g. with one primary transformer taken out of service, monitor temperatures on the second transformer supporting the total load on of the primary substation).

Impact assessment involved the modelling of the ampacity of the different assets within the trial, over conditions not easily replicated in the trial to understand how the asset would perform under heavily loaded conditions and how this would inform future planning.

Full details of the DAR technique trial are contained in the DAR Detailed Reports .

http://www.westernpowerinnovation.co.uk/Document-library/

2.3.2 Automatic Load Transfer Trial

The installed equipment comprised of: remote control equipment; current measurement devices; and FALCON Communications Network Equipment. This equipment was fitted to/used at:

- 19 substations across interconnected 11kV circuits between Marlborough Street and Newport Pagnell Primary Substations; and
- 12 substations across interconnected, largely overhead line, circuits between Winslow and Newton Road Primary Substations.

Figure 2 shows examples of the two actuator types fitted.

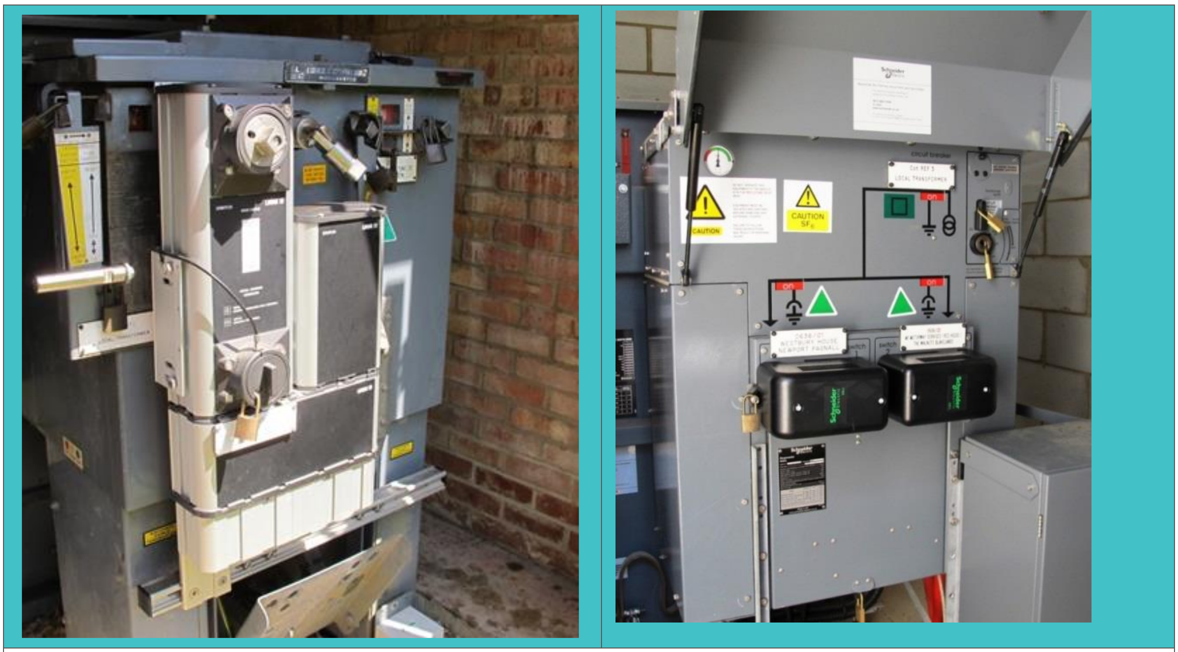

Figure 2 – Installed switchgear actuators.

The monitoring principally consisted of retrieving logged data via the FALCON communications network from:

- Source feeder current measurements (half-hourly basis) at Primary substations; and

- Along-the feeder current measurement (10 minute basis) from installed equipment at Distribution Substations;

Modelling and validation activities involved establishing offline power flow models (using the TNEI IPSA platform) of the base network; conditioning of load models for substations on the network (with scaling to measured feeder currents); and development and use of Python3 scripts to automatically adjust the time varying substation load and calculate and adjust the position of the normally open points as required. The modelling and validation was highly dependent on the scripts to handle data input and output from IPSA, control of switch states in the network models, and general control of multiple load flow cases that were generated and examined.

Operation of the assets within the trials included a series of tests consisting of: monitoring period (gathering data on pre-existing NOP positions); switching (to preferred configuration); monitoring (gathering data on preferred NOP position); switching (to pre-existing NOP locations; and monitoring (gathering data again on pre-existing locations). This “listen, change (to new), listen, change (back), listen” approach facilitated validation of results from modelling.

Impact assessment involved the modelling and analysis of the differences in network performance under pre-existing and preferred conditions, and the drawing of conclusions. Clearly the network could not be in two states (pre-existing and preferred) at any one time, so direct measurement of change was not reasonably possible, and this placed additional demands on validation within the modelling.

2.3.3 Mesh Trial

The installed equipment comprised of: additional ring main units, providing along-the-feeder circuit breakers; directional-capable protection relays with associated current and voltage transformers at both Primary and Distribution substations; remote switching equipment; temporary power monitoring equipment for trails data gathering purposes; and FALCON Communications Network equipment, to support asset data collection and high-speed protection signals. Figure 3 shows a typical arrangement of the additional RMU adjacent to an existing Distribution substation. This equipment was fitted to:

- Two feeders from the Bletchley Primary Substation 11kV board, comprising the Simple Mesh implementation;
- Three feeders from Fox Milne Primary Substation, comprising the complex mesh implementation; and
- An inter-connecting feeder between Childs Way and Secklow Gate Primary Substations.

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[3] Python is an established high level programming language that TNEI have adopted to allow users to develop scripts that can: modify electrical network models/data; use the core IPSA power system analysis functionality; and return specified study results.

Figure 3: Typical arrangement of the additional RMU adjacent to existing Distribution substation

Equipment was installed to support investigation of both simple and complex mesh examples, and the interconnection of two Primary substations. However, testing of the more complex mesh example and the Primary substation interconnection was not taken forward as originally planned due to encountered slower than designed high speed protection signalling over the FALCON communications network.

The monitoring principally consisted of logging and retrieving logged data from:

- eMS Sub.net substation monitoring equipment providing voltage, current, power and power quality averages (10 minute basis);
- Alstom P141 protection relays sampled to provide voltage, current, power indications (averaged on 10 minutes basis); and where available
- Settlement metering data aggregated to provide half-hourly demand for substations on the trial network.

Modelling and validation activities involved establishing offline IPSA models of the base network; creation of a model of actual load data pulling together data from the three monitored sources; and Python scripts handling IPSA data input and output, plus model and study control.

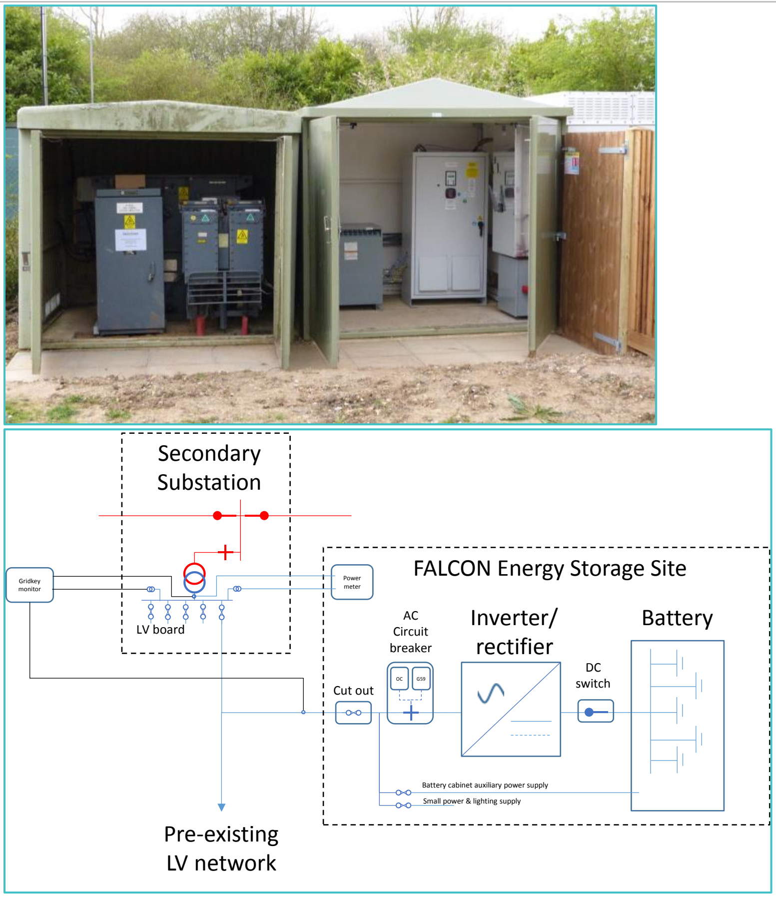
Operation of the assets within the trial consisted of closure of the pre-existing NOP at MK Dons Stadium on the Simple Mesh example circuit for pre-set periods of time. Testing configurations were dependent on normal operating circumstances at the source primary, with both 33/11kV transformers being in service, and the 11kV board bus section being closed. These conditions were met as scheduled throughout the testing periods.

Impact assessment involved the modelling and analysis of the differences in network performance with the NOP open and closed. Whilst the network could not exist in these two states at the same time (NOP both open and closed), it was possible to measure power flow at the pre-existing open point, and directly show differences between the alternative circuit configurations. In addition, modelling of the network using recorded load data provided more detailed insight, plus assessment of voltage and losses impact. Recorded power quality data was also reviewed. Conclusions were drawn from the results and analysis.

2.3.4 Energy Storage Trial

The installed equipment comprised of five energy storage units (converter with battery module) connected at existing substations on a single 11kV feeder from Fox Milne Primary substation. Each site contained: a 50kW/100kWh energy storage (sodium nickel) battery, with battery management system; a 100kVA rectifier/inverter unit; site controller (providing user interface and control functionality); G59 protection connection circuit breaker; and fused connection to the LV distribution network at the adjacent Distribution substation.

Figure 4 shows a picture of the installed arrangement at the AWA Middleton site; an electrical schematic of the Energy Storage systems and a view of the Princeton Power Systems' rectifier/inverter unit.



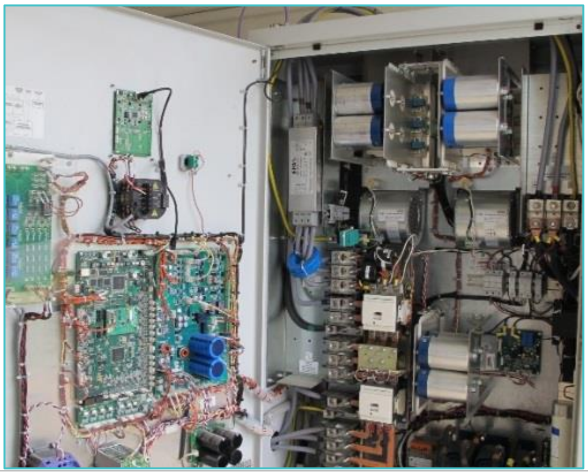


Figure 4: Selected images characterising the Energy Storage trial and associated equipment

The monitoring principally consisted of retrieving logged data from the installed LV Gridkey monitoring of the substation (including the connection to the energy storage system), plus limited retrieval of data from the data logged on the energy storage system control systems.

Modelling and validation activities mainly consisted of analysis and charting spreadsheets linked to databases. These were developed throughout the trial operation, and included, for example, development of a simple Excel tool to estimate the required peak-shaving threshold.

Operation of the assets within the trial consisted of a series of periods with the system operating in key functional modes, these highlighted and examined: basic charge and discharge operations (including audible noise, and weekly maintenance/calibration); peak-shaving functionality, both at the local Distribution substation and on the host 11kV feeder; reactive power/voltage response; real power/frequency response; and impact on power quality. Predominately these operations were conducted remotely via Microsoft Remote Desktop Connection to the (Windows-based) Energy Storage Site Controller, over the FALCON Communications Network.

Impact assessment involved analysis of monitored output of the energy storage systems, both individually and in combination, with comparison to local and feeder indications (for example power, voltage, and power quality). Conclusions were drawn from these results and analysis.

2.4 Dynamic Asset Rating - Key results and learning

2.4.1 Key findings

Key findings from the Dynamic Asset rating (DAR) trials are that:

- Tuning of thermal models was necessary to achieve agreement between model and measured asset temperatures. This tuning involved the selection of appropriate asset specific model parameter values. Selection of values was based on available manufacturer data and heuristic approaches where limited manufacturer data was available. This was particularly the case for distribution transformers, where it was found that individual asset parameters were necessary to account for the variety of physical designs within the trial examples. Figure 5 shows an example of a well-tuned thermal model for a Distribution transformer.

- Once adequately tuned, the thermal models for the asset classes included in the trials agreed well with measured parameters.

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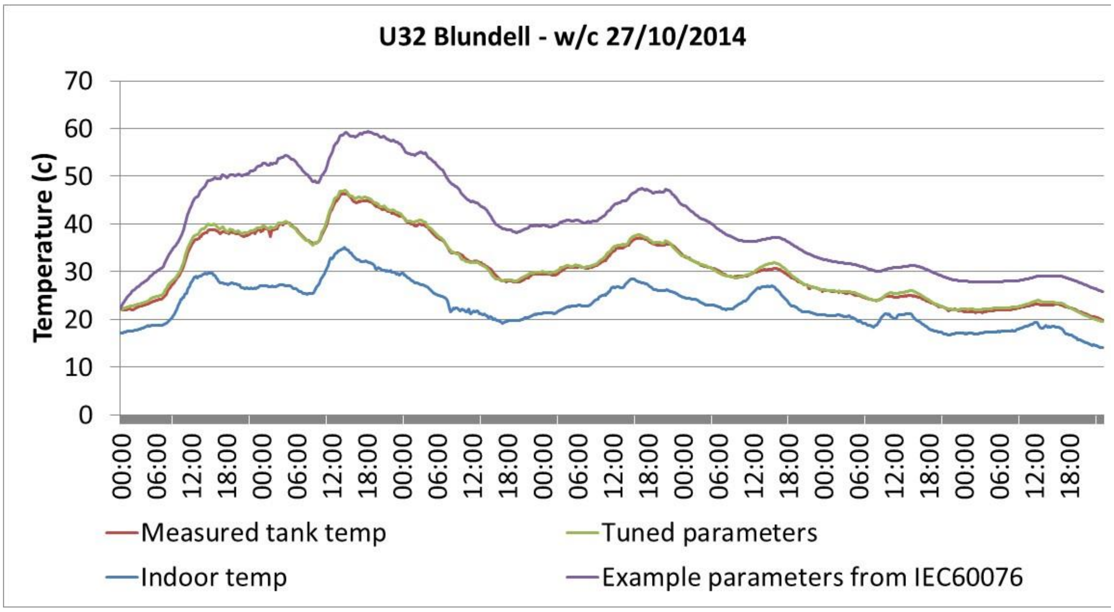

Figure 5: Measured tank temperature and modelled top oil temperature with IEC600-76 example values and tuned values indicating how accuracy can be significantly improved with tuned parameters.

- The Alstom P341 relays provided outputs with a range of usefulness. The OHL-only variant was clearly the most developed, providing both dynamic conductor temperature assessment and OHL ampacity based on a thermal model. The Transformer/cable/OHL-relay variant is regarded as less complete: cable dynamic rating assessment did not implement an online thermal model and the transformer assessment, whilst implementing a thermal model, did not calculate an ampacity.
- For all the asset types (e.g. OHL, cables, and transformers) periods of time were found where the real-time dynamic ratings[4] were above the applicable static, and there were periods when the dynamic ratings were below static ratings. For example, Figure 6 shows that for a trialled 11kV OHL all months except September saw the mean dynamic rating for the month being greater than the applicable static rating; however, the minimum real time values were lower than the static rating for the majority of months.

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[4] a rating calculated at a point in time that depends on the current thermal state of the asset, and the ambient environmental condition at the time of calculation

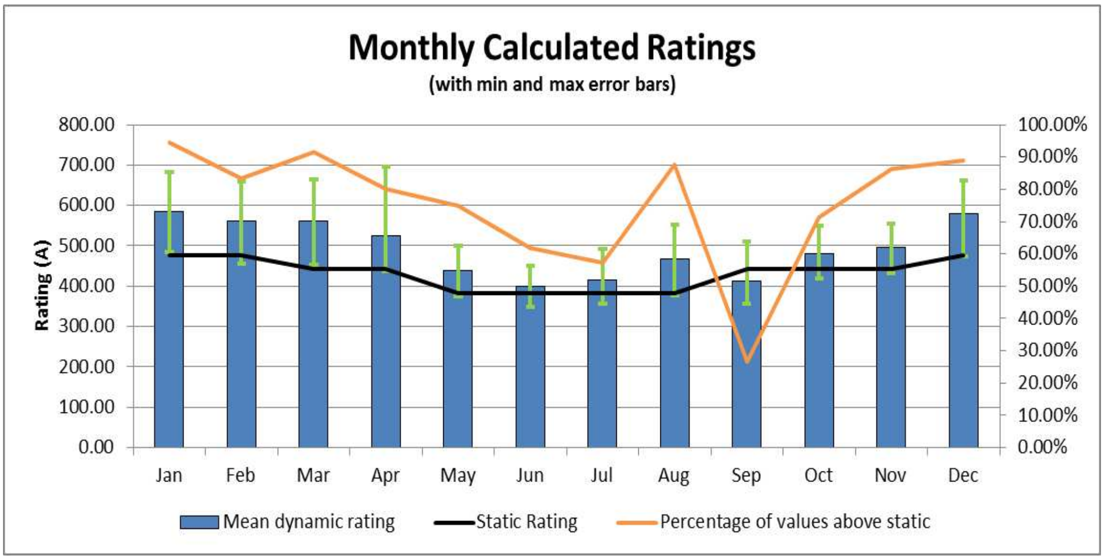

Figure 6: Variation in real time dynamic asset ratings for trialled 11kV OHL.

- Real-time dynamic ratings may be highly variable, depending on variation in key ambient conditions. High variability in rating, over short time spans, presents difficulties in network planning phases, and both difficulties and opportunities in operational phases.
- A method of estimating future dynamic ratings, developed throughout the trials, offered a means of creating reliable forward views of future ampacity, based on trial results.

Evidence and explanation of these key findings, together with more detailed findings, are presented in the DAR documents which can be found here:

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-OHL.aspx

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-Cables.aspx

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-Distribution.aspx

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-Primary-Tran.aspx

2.4.2 DAR selected Discussion and Learning

This section presents a selection of key discussion and learning points that are the basis of the DAR conclusion drawn within the overall DAR Final Reports.

All DAR assessment is predicated on a thermal model of the asset, and confidence in that model. These models include parameters that are specific to each asset class, and values for the parameters that can be specific to an individual asset. These parameter values were found to be reasonably available for all assets trialled, except for distribution transformers. Initial models for these transformers did not achieve satisfactory correlation to (oil temperature) measured values. As a result, an innovative parameter value tuning technique was developed to establish appropriate values on an individual transformer basis. The general principles of this approach would be applicable across all asset types. This subsequently gave satisfactory correlation to measured values.

The thermal models were able to predict temperatures, generally to within 5oC over 90% of the time, indicating a modelling error of better than 10%. This assessment of accuracy could be further used in subsequent work to establish operating uncertainty margin.

A dedicated DAR relay is not essential, other computing devices/systems could perform real-time assessment calculations (e.g. the network management system), if these are required. The three asset (OHL/cable/transformer)-variant relays provided limited functionality and both variants (OHL-only and three asset-variant) were inflexible. In addition, offline modelling (an alternative to real time relays) was particularly important because it allowed extension of the work into forecasting of future ampacity – see points below about forecasting ampacity.

For overhead lines, the variation in dynamic rating calculated at an instant in time was principally driven by wind speed/direction. This offers some immediate operational opportunities, but very limited long term planning opportunities (hence exclusion from SIM). However, measurement of wind speed/direction needs to be implemented with care to ensure values are representative of conditions experienced along the OHL. This could extend to the use of specialist instrumentation service providers.

For Primary transformers and outdoor Distribution transformers, dynamic ratings are principally driven by the relatively slow moving ambient air temperature, and the time constants are hours in duration. The trial results suggest that over the winter period there is scope to run the transformers with a 10% increase in rating, but with a lower rating in the summer. It should be noted that whilst modelled top oil temperatures were validated against measured values, this validation was not possible for winding hot-spot temperature5, the thermal limit, and basis for life-usage assessment.

For transformers located in indoor Distribution substations, trials suggest that for many sites the (indoor) ambient air temperature is above standard assumed values that form the basis of ratings. The implication of this is that many of these transformers are operating with hot-spot temperatures above what would have been expected for their electrical load. However, this does not imply that they were operating above the nominal

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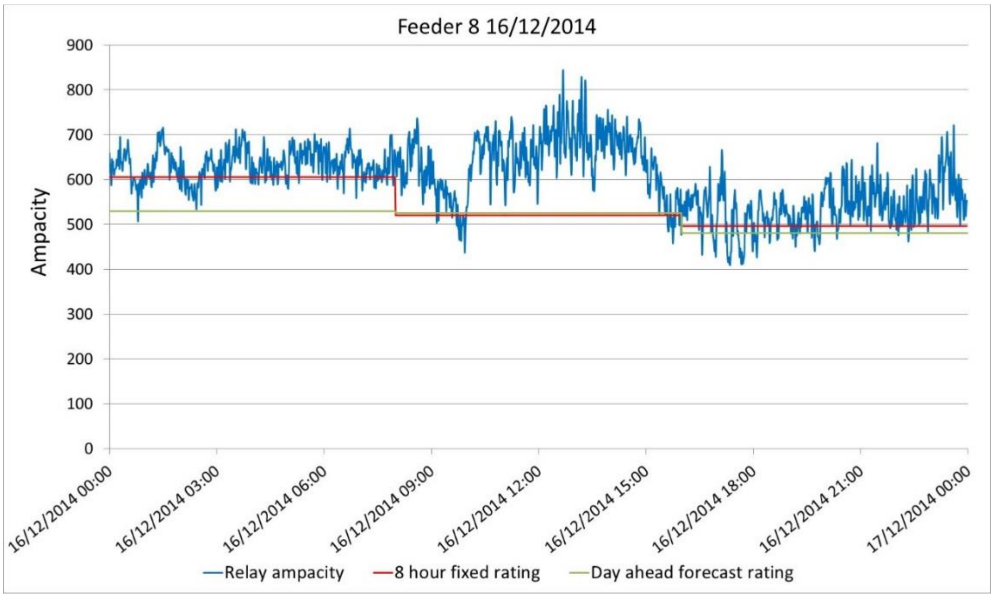
[5] The winding hot-spot is the hottest point in the electrical winding of the transformers. The position of the hot-spot can vary, and is not measureable without specialised provision, generally only possible at asset construction stage.

life usage rate temperature of 98oC. Reducing this air temperature (towards surrounding outdoor air temp) would tend to reduce experienced hot-spot temperatures, reduce life-usage, and could have a significant ratings benefit.

The dynamic asset rating associated with cables appears to offer up to 7% increase in (sustained) static rating in winter months. Investigation of the experienced cyclic loading suggests that the load curve shapes seen on the trial assets had a higher minimum load and suggests that there is less DAR benefit with cyclic rating than sustained rating over the winter months. Further investigation is recommended.

A limitation in the practical application of real-time dynamic ratings is the variability that was experienced. This was particularly the case for overhead lines where the key determinant of variation (wind speed/direction) could change very quickly, and with the asset having low thermal capacity, consequential conductor temperature changes can occur quickly (within moments). This led to consideration of the ability to estimate future ampacity, and the development of an approach that was implemented for each of the trial asset types. The approach takes ambient parameters[6] from weather forecasts and provides shapes to these values over time. From the arrays of shaped ambient conditions, a profile of maximum current values is iteratively calculated that causes the asset to heat up to its limiting temperature (allowing for an uncertainty margin). This maximum electrical current profile allows the ampacity of the asset to be assessed based on the forecast time-varying ambient conditions. This method of estimating future ampacity was tested by comparing the forecast ampacities against outturn real-time ampacities and found to provide a satisfactorily reliable indicator.



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[6] Wind speed & direction, air temperature, and solar irradiation for OHLs; air temperature for transformers.

Figure 7: Figure showing real-time ampacity with fixed 8hr rating based on this and the 8hr rating based on day ahead forecast data (static rating = 476A).

With respect to learning that shaped the SIM, generalisation of thermal modelling of cables within the trials provided size-scalable construction-specific models that enabled the widespread assessment of cables in the SIM network area. In addition, a range of parameters amendments were proposed for transformer DAR algorithms, based on learning from operating experience.

Further discussion and points of learning are presented in to the detailed reports which can be found here:

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-OHL.aspx

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-Cables.aspx

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-Distribution.aspx

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-DAR-Primary-Tran.aspx

2.5 Automatic Load Transfer - Key results and learning

2.5.1 Key findings

- Improvements in 11kV capacity (at first branch out of the primary) are possible, an example is shown in Figure 8. These improvements are dependent on the algorithm used, the load balancing algorithm (method 2) gave superior results to the losses reduction algorithm (method 1). On the overhead network an improvement of four percentage points for the most heavily loaded feeder, and twelve percentage points for the second most heavily loaded feeder were seen during the ALT technique trial test period. On the underground network a reduction of eight percentage points was achieved on the most heavily loaded feeder, and the three most heavily loaded feeders balanced to within three percentage points were seen during the ALT technique trial test period. Reductions in maximum (of any) feeder loading can be expected around the year using this approach.
- Improvements in 11kV losses are also possible. Improvements are again dependent on the algorithm used, method 1 improved losses, method 2 (designed to improve capacity) worsened losses. Improvements are found to be up to 12% using method 1. It is not practicable to directly measure losses on the Network without measurement at each substation. Therefore losses, and benefits in losses, must be modelled.

- Voltage improvement was also achieved under method 1. This is more noticeable on a rural overhead line Network, and was marginal in magnitude on the trial networks;

Customer numbers per feeder varied consequentially according to the algorithms developed to improve losses/voltage, and capacity. Depending on the specific network, potentially more customers are at risk of being impacted by a fault if the Network is reconfigured to reduce losses or increase capacity headroom. This could be simply mitigated through implementation of along-feeder staged protection.

It seems possible that much of the improvements that have been indicated from these technique trials could be captured through one-off adjust to NOPs, though the trials do indicate that further (more marginal) benefit may be obtained by implementing within day, over the week, and across season changes to NOPs. Where the analysis shows potential variation in switching points (across the day, within week or across seasons) then the potential switching points are closely clustered. It is considered that further load monitoring would have to occur around the indicated switching points to conclude if these additional modelled benefits really existed, and their magnitude relative to the complexity that would be required to capture them.

Whilst networks could be optimised to improve capacity ahead of need, there is no benefit in doing this in preference to optimising for losses/voltage. ALT could be considered as a strategy for improving capacity headroom, but only as feeders approach thermal limits.

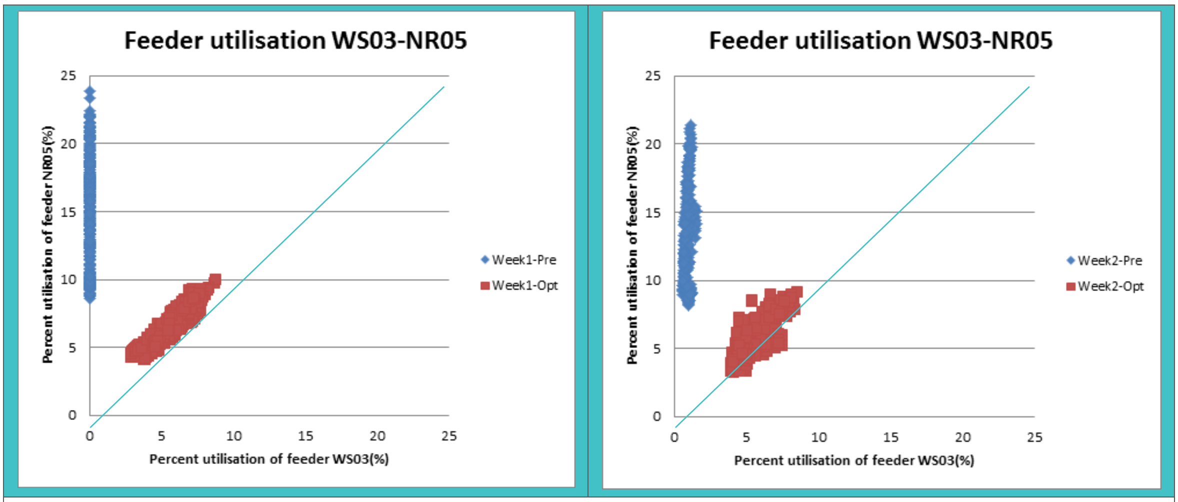


Figure 8: Measured and modelled feeder utilisation for trial week 1 with the pre-existing configuration (Pre) network topology and for trial week 2 with the calculated configuration (Opt) showing a modelled and measured reduction in feeder utilisation from Newton Road feeder 5 of over 10%

2.5.2 ALT selected Discussion and Learning

This section presents a selection of key discussion and learning points that are the basis of the ALT conclusion drawn in the ALT Final Report. Further discussion and points of learning are presented in the ALT Final Report.

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Engineering-Trials-ALT.aspx

- Extensive data collection, NOP selection algorithms, modelling and model validation are all required to identify alternative NOP positions. This includes up-to-date network models, accurate technical parameters for the network, and models/measurements of load and particularly generation. The accuracy of outcome (NOP positions) is highly dependent on the load measurement/model used.

This detailed modelling should be completed ahead of determining the need for/location of additional remote switching. These trial results showed that preferred NOP positions were either found at specific points, or over a number of adjacent switches, rather than generally distributed across the network. Remote switching (and potentially additional circuit sectioning points on OHL networks) should then be installed at these modelled points of interest/benefit.

Benefit assessment, and validation of the assessed benefit, is not straightforward. It is not possible to directly measure an improvement that would arise from implementing an alternative NOP configuration. The loads will always be marginally difference between the two test periods, and inference of improvement from modelled results is the basis of our findings. A novel method of validating benefit assessment has been developed and used.

That two algorithms were required to optimise for different criteria illustrates well the complexity inherent in modelling for ALT. It is paramount to appreciate that the indicated ALT benefits are not all simultaneously realisable.

Changing open point locations to improve capacity on the first branch out of the primary may have adverse impacts on branch loading close to pre-existing NOPs, if the network is tapered.

Because of the nature of overhead networks (permanently connected pole mounted transformers) there are less network switching points, and therefore the resolution of changes for the overhead network is coarser compared to the UG network

There is some possibility that the variation of preferred NOPs is related to the loads of small numbers of larger consumers. This raises the possibility that the exact location of the preferred open point may be directly related to the load at a single site. This in turn raises the possibility of defining real-time preferred open points based on single site or switching point measurements with trigger points, though thresholds/trigger points for change would have to be determined through extensive modelling and/or practical testing. Benefit analysis could only be undertaken with network modelling.

Generation potentially has a very significant impact on the network, and preferred open points. It is therefore essential to understand its running regime.

Future variation in the magnitude and profile of loads and connection/change in distributed generation implies the need for ongoing monitoring/re-assessment of optimum NOPs.

Further development and validation of the technique needs to occur before it could be used in a planning environment. A potential route would be: deployment of the technique on a section of network that has capacity issues, and develop algorithm/solutions in collaboration with local planners.

2.6 Network Meshing

High level results from the Mesh trials are that:

- Meshing of a simple (two feeder) network changed loading on the source breakers, but not to reduce load on the more heavily loaded source during peak load periods;
- Voltage and power quality (PQ) were found to be largely unaffected on this small compact urban network. In general, it may be expected for there to be only marginal change in these respects;
- A 5% reduction in losses was estimated on this trial network, though this should not generally be assumed to be the case (dependence on relative feeder impedances);
- High-speed protection communications over the FALCON communications network did not operate as expected; and
- Security/reliability was maintained compared to the pre-existing condition, through the installation of a protection relay operating on an overcurrent basis at the trial-installed circuit breaker closest to the NOP. The trial was not able to implement additional sectioning as originally planned due to encountered slower than designed tele-protection signalling on the FALCON communications network; and limits in achievable certainty within conventional protection discrimination (i.e. without interconnection of relays).

2.6.1 Mesh selected Discussion and Learning

Whilst the sharing of total circuit load between feeders is entirely predictable, it does not necessarily tend to equalise load across feeders, as might be thought. This can be seen in Figure 9 which shows the power flow through Bletchley – Granby Court increasing under meshed operation (solid line) compared to the unmeshed state (dashed line).

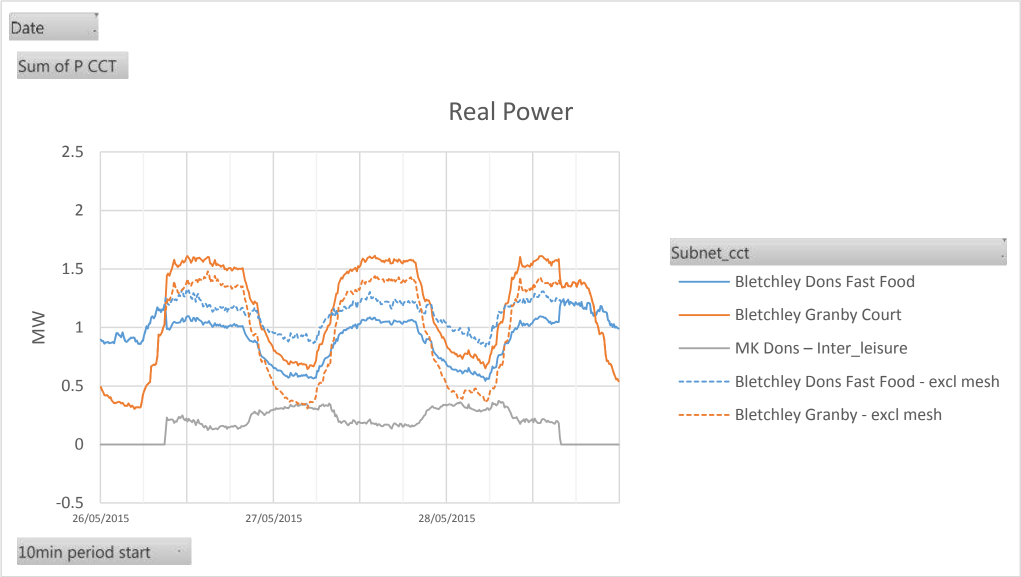


Figure 9: Graph showing the real power flow through the two feeders of the meshed Network.

Within the trial, although half-hour periods of improvement in capacity headroom were found, these periods only occurred during minima in daily feeder loading. Therefore no useful improvement in capacity headroom occurred on the trial circuit.

Installation of circuit breakers and directional-capable protection relays imposes complexity and on-going operational/maintenance requirements (e.g. additional ring main units, star connected VTs, and tripping batteries at Distribution substations).

2.7 Energy Storage

High level results from the Energy Storage (ES) trials are that:

- Reliable peak-shaving at individual sites was repeatedly achieved (Figure 10a), and combined ES systems discharge also reduced the peak at 11kV feeder level over successive days of high winter demand periods (Figure 10b).
- Manufacturer set-points of 50kVAr resulted in limited measurable voltage response impact on LV voltage (Figure 10d);
- ES was found to increase losses in aggregate (considering both feeder I2R losses, and ES system losses);
- Frequency response was demonstrated for both above and below 50Hz (Figure 10c);
- PQ was improved at one site (highly circumstantial relating to the specific disturbing load, and the sizes of inductors and capacitors within the ES system), though not at the other more representative monitored site;

2.7.1 ES selected Discussion and Learning

The trial has highlighted that battery chemistry and manufacturer design philosophy impacts greatly on performance characteristics (e.g. differing charge/discharge rates, auxiliary power loads and consequential efficiency, battery calibration/maintenance requirements). This results in a trade-off between purchase cost/operating cost/battery life span/specific technical requirements (such as ramp rates). It is recommended therefore that future functional requirements for battery systems remain open ended at this time (until battery chemistry becomes more established) to ensure battery purchase is not too restrictive. In addition, it is recommended that particular use of reference sites is made, so that operating experience can be judged.

Good availability of technical performance parameters (including battery state of charge) and data logging from the battery management system are key on demonstration and research projects and a clear and detailed discussion with the manufacturer on proprietary data (both for access and dissemination) is recommended prior to purchase.

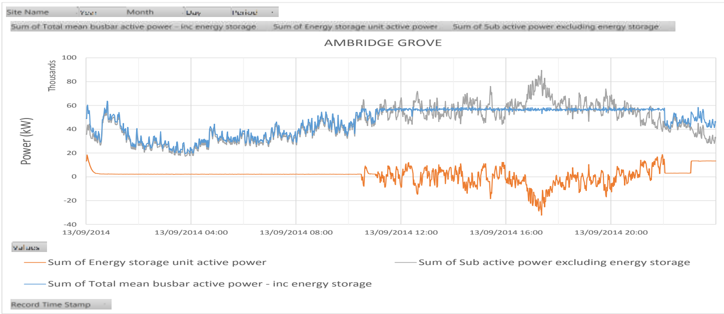
At 11kV, and for fixed systems, a single site energy storage system (if a suitable site can be found) would simplify the challenges of installing/commissioning multiple times, and complexity of control equipment coordinating across multiple sites. However a dispersed site could offer the same functionality while potentially improving on availability and make it easier for customer owned energy storage assets to be integrated into Network management.

- Peak shaving:
  - The technique trial effectively demonstrated the capability of energy storage systems to shift load in time, reducing load at a capacity constrained key point in time, and increase the load at a less critical point in time
  - Whilst trials have demonstrated the capability of energy storage to effectively peak-lop, the trials also show that the trigger thresholds used are only effective (i.e. only call the ES into service) for a relatively small number of weeks in a year. Outside of this period the equipment is not required (for capacity), and could be used for other purposes such as frequency response.
  - Peak-shaving at individual substations is dependent on: assessment and forecasts of future load; decisions about the available state-of-charge; and magnitude versus duration of the targeted peak reduction. For a fully operational device, this functionality should be specified as an adaptive peak-shaving controller.
  - Peak-shaving of an 11kV feeder that involves coordination of multiple ES systems is broadly similar to the requirements for peak-shaving at an individual site, but requires additional control logic that allocates the operation out to the individual sites (factors to consider in the allocation to individual sites include: initial state of charge; life management of individual batteries; and site outages).
  - The trial showed that it is difficult to measure and demonstrate the impact of reactive power output on LV network voltage (given the installed capacity), and consequentially a method of assessing voltage-differentials across adjacent sites was developed.

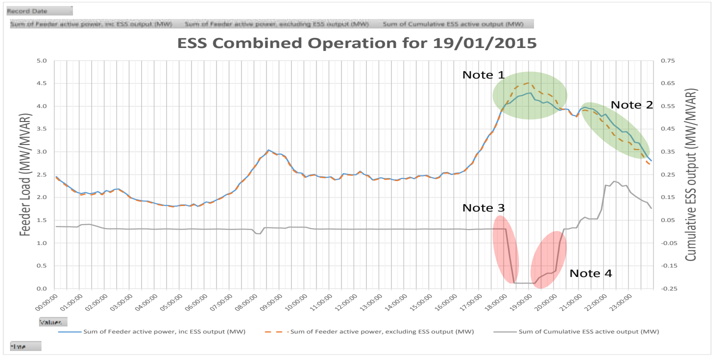
Frequency response:

- the trial demonstrated a capability to deliver frequency response, as one example of potential ancillary service provision.
- considerably more work, beyond the scope of FALCON, would be required to detail service capability in this area. Details would include: linearity of response to high/low frequency (and how this varies with state-of-charge); number of events per day, duration/energy content of events, optimum state-of-charge that frequency response would start from (to allow by high and low frequency response) and impact on life;
- where multiple battery units are envisioned, it seems likely that multiple registrations and multiple metering arrangements would also be required. Dispersed installation might also challenge prevailing commercial arrangements, with aggregated operation not being recognised commercially.

Audible noise was also a concern with the equipment and its locations. Work with the manufacturer led to modified inductors being fitted to the converters which reduced audible noise. The construction and electrical size of such components is clearly important to achieving satisfactory performance.



(a)



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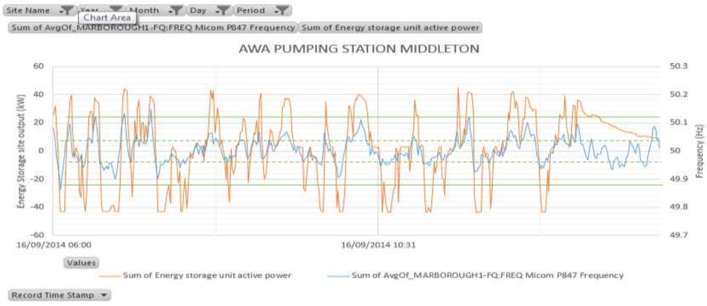


(c)

(d)

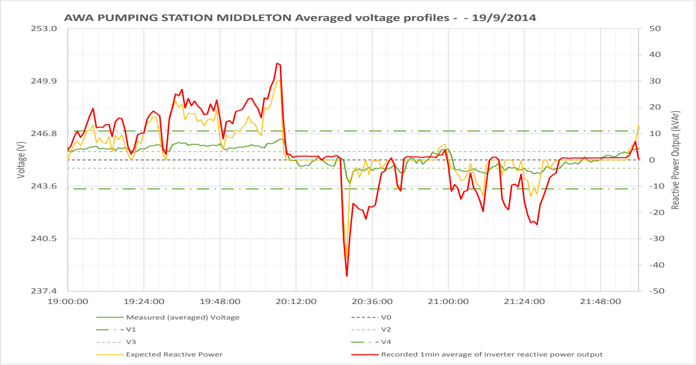


Figure 10: Selected charts characterising results from the Energy Storage trial

2.8 Cross-technique comparison of impact

Table 1 provides a high level summary of which techniques impact what network metric, with the remainder of the section providing comparison of the DAR Cable technique with other trials, on a network-metric basis

	DAR - OHL	DAR-Tx	DAR-Cables	ALT	Mesh	Energy Storage
Thermal limits /capacity headroom	✓	✓	✓	✓	~	✓
Voltage limits	No impact	No impact	No impact	✓	~	✓
Fault levels	No impact	No impact	No impact	No impact	✗	✗
PQ	No impact	No impact	No impact	~	~	✓
Enablement of DG	✓	✓	✓	✓	✓	✓
Losses	✗	✗	✗	✓	✓	✗
CI/CMLs	No impact	No impact	No impact	~	~	No impact
Grid/ network services	No impact	No impact	No impact	No impact	No impact	✓

Key: ✓Positive impact; ✗negative impact; ~ network dependant, may have positive or negative impact

Table 1: Cross-technique comparison of impact.

Network capacity:

- All techniques altered capacity on the network;
- DAR evaluates capacity more accurately than static ratings which may suggest additional or in some cases less capacity. OHLs are predominately affected by wind speed/direction meaning significant variations occur both across seasons and within short time scales (minutes). When this variability of rating is combined with the low thermal capacities of OHLs (i.e. the OHL temperatures respond rapidly to the environmental changes), taking advantage of this technique is limited to particular circumstances. The dynamic ratings of both cables and transformers are dependent on ambient temperatures, meaning diurnal (for transformers only) and seasonal variations are clearly present, and the larger associated thermal capacities means short-time duration changes in ambient conditions cause less short term variability in asset ampacity;

- ALT and mesh shift load from one part of a network to another, thereby potentially relieving constraints. ALT offers a far more intuitive mechanism, whilst mesh is continually dynamic by its very nature. The extent to which benefits exist is highly dependent on the connectivity of any candidate network, and loads/generation connected to the network, and the extent to which the loads vary relative to each other; and
- Energy storage shifts load in time, reducing load at a capacity constrained key point in time, only to increase the load at a less critical point in time. The specified power and storage energy capacity clearly need to be appropriately matched to the network load; and adaptive triggering is required to deal with individually daily variations in load, to optimise the impact that the installed system can have on the network. Energy Storage may complement DAR by providing a mechanism to alter load patterns such that constrained assets might make the best use of available ampacity.

Voltage:

- Three of the techniques offer some potential for benefits (ALT, Mesh, ES);
- ALT demonstrated the largest benefit (4%), on some of the rural circuits that were trialled, but no significant benefit was found on urban circuits;
- Mesh considered a small urban network and for this example there was no significant impact on voltage;
- In general the voltage benefit of the ALT and mesh techniques networks will depend on the voltage difference across pre-existing NOPs, and does not directly address voltage issues at the end of branches
- The installed energy storage systems achieved little impact. In general, the reactive power capacity in relation to the magnitude and power factor of the adjacent load is modest, and can be expected to be expensive to deliver for this benefit alone.

Fault level:

- As is clearly already recognised, introducing generation (including ES) to a network will ordinarily increase fault level, in this instance the ES were small compared to pre-existing fault levels, and so had negligible impact. Meshed networks will also increase fault level due to the reduced circuit impedance. For the mesh technique trial, this was within the ratings of all circuit equipment.

Power Quality (PQ):

- Mesh trials showed no discernible impact on power quality. Super-position theory and the feeding of harmonic loads via different sources means that harmonics presently fed from one source could be fed from two sources (depending on Network impedances), however, it is unlikely that larger scale trials will show any marked appreciable benefits as the majority of loads are within limits defined by standards and as such it will be difficult to differentiate small changes;
- The installed energy storage equipment did not specifically have functionality aimed at improving PQ. At one site, improvement was noted, however this was a beneficial

coincidence arising from the nature of a local (within standards) PQ disturbance and the inductance/capacitance smoothing network in the Energy storage system;

- More targeted studies of a network that has a known PQ issue could be identified to further examine the potential of mesh/ALT techniques to beneficially impact this issue.

Enablement of DG:

- This was not specifically studied as part of the engineering trials (e.g. interaction between the engineering techniques and DG was not designed into the trials);
- Whilst not a direct focus of the FALCON trials, it is clear that DAR systems may offer potential benefit to distributed generation, but is highly dependent on circumstances. For example, OHL DAR can increase export from OH connected wind farms on a windy day; but solar farm output peaks occur on clear summer days when DAR OHL is less likely to provide additional benefit;
- ALT may facilitate the connection of more distributed generation. However, this needs to be looked at on a case-by-case basis as the location of the generation along the feeder, in relation to the ratings and load, can have an impact. Where the generation is close to the source (such as in the FALCON ALT OHL trial), there is scope to add a significant amount of generation so that the feeder is able to export at the Primary and also meet the load requirements along this feeder. The nominal location for the open point may well be different between when the generation is running or is off and this may impact other metrics such as losses and voltage regulation if generation operating condition is not considered.
- Meshing may facilitate the connection of more distributed generation by providing a second export route in certain scenarios, thus saving on line and cable upgrades. Modelling also indicates that there may be cost savings from reductions in feeder losses when meshing a network with DG connected to one feeder. However, the benefits of reduced losses would have to be compared on a case-by-case basis with the costs of more complex protection required for meshing (potentially necessitating replacement of existing protection relays as well as new relays).
- ES systems offer potential benefit to distributed generation. Examples of this include: peak generation lopping - storage of peak energy production (say above connection agreement levels) for later injection to the grid; and storage of energy to allow market arbitrage.

Losses

- As discussed in the preceding technique-trial specific section, ALT and Mesh offer some potential, though the magnitude is network specific.
- The trialled ES systems increased losses, and DAR will tend to increase losses if higher circuit loads are facilitated.

CIs and CMLs

- ALT changes NOP positions and consequently affects numbers of connected customers per feeder. The trial algorithms:

  - Increased one feeder numbers by 15% (whilst optimising capacity headroom) on a rural/OHL network; and
  - Increased one feeder numbers by 50% (whilst optimising losses/voltage) on an urban/cable network.
- Meshing networks does not improve customer security as such; the improvement only occurs if additional automatic sectioning/unitising occurs beyond that offered by the pre-existing NOP. Due to communication system limitations, the implemented trials did not increase the number of sections, essentially maintaining the pre-existing customer security.

Grid/network Services:
Whilst these trials have demonstrated that frequency response is possible with the ES technique, a marketable service is not fully delivered by the installed equipment. In addition, further work would be required to put DNO owned energy storage on an appropriate commercial basis. Refer to the WPD Solar Store NIA project.

2.9 Other generalised learning

Measurement and data strategies are important to the validation of trialled techniques, and require careful attention in both the solution outlining phase and detailed design phases. Examples of this include:

- Data acquisition and storage methods for Distribution transformer temperatures, including assessment of local acquisition with store and forward, versus remote acquisition and central storage;
- Sampling rates and averaging of data (appropriate to the purpose behind data collection), and strategies for dealing with unavailability of data;
- Tabulated specification of technical parameters associated with the ES systems, confirmed feasibility of data availability, extraction, transmission and storage.

Determining Network benefit within a trial is complicated by the continuously changing load and voltages on the Network and the small scale size of the techniques in relation to the Network. An approach of:

  - Measure parameters;
  - Add equipment; and
  - Re-measure parameters to determine benefit

is not applicable for many of the techniques. This results in the need to determine innovative techniques encompassing a mixed modelling/measurement strategy to show benefit.

2.10 Conclusions and recommendations

The engineering trials within the FALCON project demonstrated and explored four innovative techniques aimed at relieving technical constraints on 11kV network. The trialled techniques are alternatives to conventional reinforcement, the usual engineering remedy to network constraints.

Each technique trial was composed of: equipment purchase, installation and commissioning; monitoring; pre- and post-operation modelling and validation; operation of assets; and impact assessment. In doing this, the trials informed the FALCON SIM about how such techniques could be modelled. Network in the Milton Keynes areas was selected as: an area with strong low carbon ambitions; providing examples of typical 11kV infrastructure but not actually under constraint. This absence of constraint provided time to investigate the techniques appropriately.

- Dynamic asset rating associated with primary transformers and outdoor Distribution substation transformer appears to offer up to 10% increase in rating at times of year when there is generally higher load, and as such could offer potential for further development. Such development could be targeted at existing transformers that are approaching thermal/load limits, and would involve: limited installation of temperature & load monitoring; tuning of transformer specific models; and assessment of potential to run at higher than nominal ratings.   Such development would include addressing the issue of risk management with respect to transformer life. With this method, there may be a small number of days where the ambient temperatures are materially above seasonal averages, and if these coincide with high loading, accelerated (vs par) life usage may occur on such days. It is recommended that further work should initially focus on a candidate primary transformer to trial actual solution provision (to an asset nearing capacity) and demonstrate actual benefit delivery. A candidate outdoor Distribution transformer could also considered, where a higher life risk strategy towards estimated operating hot-spot temperatures (given the lower asset cost) could be trialled.
- Dynamic asset rating of indoor Distribution transformers also appears to offer some potential. This potential could be further proven by taking specific examples of Distribution substations approaching thermal/load limits, installing simple monitoring and assessment equipment and specifically look at improving ventilation as a means of enhancing available capacity. Whilst issues/failures in this class of assets is currently not a key issue, future growth in electricity demand (e.g. electric vehicles) could substantially alter the situation.
- Whilst it has been demonstrated that ampacity of 11kV OHLs can be assessed for future periods, based on weather forecasts, improvements in ampacity are essentially dependant on wind speed/direction, and cannot be relied upon if reasonable planning certainty of capacity is required. It is recommended that 11kV OHL DAR should not be considered a feasible technique for solving 11kV distribution network issues at this time.
- Work completed under this project suggests that the dynamic rating of the trial cables may be higher than P17 sustained ratings during the winter months, and whilst improvements on a cyclic basis also exist, they are not as large due to the experienced load curve.
- ALT achieved reductions in losses on both the overhead and underground trial networks. It is recommended that these FALCON NOP positions are adopted on the network.

- ALT appears to offer potential to reduce losses through a one-off/occasional re-assessment of NOP position across the network. Further work would be required to complete specification of cross-network data requirements, and consolidate modelling algorithms for bulk network assessment purposes. It is recommended that the potential of such an exercise is further considered.
- ALT also appears to offer potential to optimise a network that is approaching thermal limits.   It is recommended that a candidate portion of network could be assessed using this technique to trial actual solution provision, where network is currently approaching/is at limits.
- The completed mesh trials suggest the potential to affect the key issue of network capacity is highly network specific. The installed equipment provides an excellent platform for testing other high-speed protection signalling communications technologies, and it is recommended that this infrastructure be retained in a mothballed state whilst the key system provider (Cisco) continues work in this area.
- Whilst energy storage has been shown to improve network capacity headroom over peaks, the experienced costs within the trial are high. In view of the reductions that have already occurred in energy storages prices, and that further reductions are anticipated, it is recommended that technology tracking in this area is carried out, to monitor for key changes in: capability/cost; practice of connected customers downstream of the meter; and development in market practice (including second-life batteries). A follow on project investigating the interfacing, metering, control and energy management of multiple customer battery units operating to provide capacity headroom at a feeder in conjunction with frequency support (to provide an income stream outside of this) would assist with accelerating remaining operational issues of energy storage within the grid.   However, in view of the changes in technology, it is recommended that this is undertaken in conjunction with a mixed set of battery technologies, so that impacts of different battery chemistries can be investigated in regards to energy management and aging in multiple operating modes.

2.11 Overview of technical dissemination

The following papers have been presented or published as part of the knowledge dissemination activity:

- “Thermal Modelling for Dynamic Transformer Rating in Low Carbon Distribution Network Operation”, IET, PEMD 2014
- “Sizing Energy Storage on the 11kV Distribution Network”, IET, PEMD 2014
- “A Practical investigation into Distribution Network Power Quality improvements from an inverter connected energy storage system without active filtering”, UKES, Warwick, Nov 2014
- “Energy Storage Trial Operation Experience on the 11kV Distribution Network” UKES, Warwick, Nov 2014
- “Energy Storage – a UK learning perspective” presented at in Hamburg February 2015 at the ACI's Energy Storage Summit

- "Experience of Availability for Sodium-Nickel based Energy Storage", IET, RTDN conference, Birmingham Sept 2015
- “Predicting Practical Benefits of Dynamic Asset Ratings of 33kV Distribution Transformers”, IET, RTDN conference, Birmingham, Sept 2015
- “Application of Automatic Load Transfer on Feeder Utilisation Balance”, IET, RTDN conference, Birmingham, Sept 2015
- “Weather Forecasting to predict practical Dynamic Asset Rating of Overhead Lines” , IET, RTDN conference, Birmingham, Sept 2015

“Dynamic Network Rating for Low Carbon Distribution Network Operation – a UK Application”, IEEE Trans Smart Grid, Jan 2015, p. 988-998

SECTION 3

Commercial Trials

3.1 Executive Summary

With the growth in all types of low carbon generation, such as wind and solar photovoltaic (PV), and the introduction of new demand technologies such as electric vehicles (EVs) and heat pumps, Western Power Distribution's (WPD) electricity network is expected to see unprecedented swings between peaks and troughs of energy usage in localised areas.

WPD's Project FALCON has examined a range of innovative alternatives to conventional reinforcement that might be used to mitigate the impact of such energy usage. This was undertaken firstly through physically trialling four engineering and two commercial techniques. Secondly, innovative alternatives where examined through building and operating a software tool. This tool: models the real network under a range of energy use scenarios out to 2050; identifies network constraints that arise over time; employ the studied techniques to mitigate constraints; and assesses impact and benefit.

This report is one of a series describing the six technique trials, and focuses on the two commercial techniques both of which can be classed as types of Demand Side Response (DSR).

- Load Reduction
- Distributed Generation

DSR is an approach that uses the management of customers assets and behaviour to support the network rather than investing in engineering techniques and infrastructure. Commercial agreements are established with suitable customers who can respond to an explicit signal and either reduce their site demand or increase their own local generation in order to alleviate demand from the network. In return for participating in the active operation of the network the customer sites have the opportunity to earn a new income.

Key learning is as follows;

DSR can't be measured in a direct comparison with conventional reinforcement as it is

- funded by Operational Expenditure rather than Capital Investment;
- requires the participation of suitable third parties which limits where it can be applied at 11kV;
- unlikely that acceptable reliability levels can be achieved;
- can't be guaranteed to over a longer term as an enduring solution

DSR participants can use their capability to earn income or avoid energy related charges from various schemes. These include programmes funded by National Grid and Energy Suppliers, which can be accessed directly or through a growing number of aggregators. This can make it very hard for a participant to understand what is the appropriate arrangement for them and contractual conflicts between programmes can mean the optimal combination is not possible.

Acceptable reliability is not possible at 11kV, as in most circumstances a single third party asset would be a single point of failure due to the limited availability of suitable participants. The cumulative impact of multiple 11kV connected participants does however suggest a far more attractive proposition to manage the higher value 33kV infrastructure.

Participants in DSR schemes are generally very positive about the arrangements and recognise the benefits of their role within such schemes.

Recommendations resulting from this report are;

- The ‘use case’ DNOs for the application of DSR is to manage temporary or transient constraints or to reduce risk until a more certain business case is achieved to justify an enduring solution from conventional and new smart engineering alternatives.
- Further work needs to be carried out between the key stakeholders that are likely to want to utilise DSR in order to ensure that operational frameworks are as inclusive as possible. If participants are willing to work within multiple programmes in order to maximise their own benefits, but also bring economies of scale to reduce the cost to consumers, then there is a duty to establish non-exclusive contracts, commercial arrangements and regulation that facilitates this.
- While it is unlikely that single I&C participants will be acceptable to manage 11kV constraints, the trials have demonstrated that they have far greater potential when aggregated to support 33kV. This can also be extrapolated to indicate similar potential if small business and domestic consumers could be aggregated to address 11kV constraints. Further research would be required to be carried out in relation to this.

The detailed report for the Commercial Trials can be downloaded from here:

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Commercial-Trials.aspx

3.2 Demand Side Response Description

It is important in establishing the context of the commercial techniques scope within the overall FALCON trials to take a step back and clarify what the definition of the term DSR represents within the UK Electricity Industry.

Ofgem have previously published a consultation entitled ‘Creating the right environment for demand-side response’ (June 2013) in which the following definition was offered.

What is demand-side response?

For the purposes of this document, we define demand-side response as actions by customers to change the amount of electricity they take off the grid at particular times in response to a signal. As such, we refer specifically to ‘transactable’ demand-side response, where a customer chooses to change the way they consume energy. This could include choosing to change their behaviour and habits to alter their energy consumption, or choosing to let somebody else help them manage or control their energy consumption. These examples differ from (‘non- transactable’) system management activities that cause no discernible change in the quality of electricity supply and in which a customer has played no part. Transactable demand-side response differs from interruptions to customers’ electricity supply that they have not chosen to incur such as rolling reductions or ‘blackouts’ that are often implemented around the world when energy shortages become critical.

In this context DSR excludes mechanisms such as time of use tariffs or other set incentives that encourage a more permanent behavioural change that requires no dynamic signal or active response.

Furthermore the Introduction section of the consultation document provided the following justification for the regulator’s interest in gaining a greater understanding of the current environment for DSR provision.

Why is demand-side response important?

Customers have always had the potential to shift their demand. Now this potential is increasing for a number of reasons, as set out below. As it does so, new potential competitive opportunities materialise, offering an avenue for innovation and new products.

- **The electricity system is being upgraded**. Ofgem has estimated that due to plant closures and the need to replace and upgrade the UK’s electricity infrastructure, over the next decade the UK electricity sector could need around £110 billion of capital investment. Demand-side response provides one way to reduce or delay some of these investment costs, which will ultimately be passed through to customers’ bills. Furthermore, demand-side response may be a valuable tool, alongside others, for managing the increasing contribution that intermittent generation is expected to make to the generation mix.

- **We are changing the way we use electricity.** As more heating and transport is electrified over time, overall electricity consumption is expected to rise, as well as consumption at peak times. The technologies behind this electrification, such as heat pumps and electric vehicles, could make it easier for customers to be more flexible about how and when they consume electricity.
- **Smart meters will open up opportunities.** Larger non-domestic customers already have advanced metering, which can help to lower the cost of monitoring and verifying demand-side response. The Government's ambition is for all households and other small energy customers to have smart meters installed by their energy suppliers by 2019. Smart meters will provide new opportunities for domestic customers to improve their understanding of their energy consumption, by giving them better information about their consumption, in a more accessible form. Half-hourly consumption data from smart metering could make contracting for demand-side response easier by providing a means to verify changes in consumption. Furthermore, a combination of two-way communication and potential load-switching functionality provided by smart metering could provide opportunities for customers to negotiate new types of contract, for example to limit their load in some way.

In addition to the introduction section of the Ofgem consultation we would also highlight that the changes to generation are just as significant as those relating to how we consume. As the volume of electricity generating capacity shifts from large scale, centralised, thermal plant connected at high voltage to distributed infrastructure the operational challenges differ. With centralised generation the network required to provide a conduit that was capable of carrying power largely in one direction, but with adequate capacity to meet the demand on the worst days of winter. The power stations enabled the system to be controlled relatively easily as the majority could be modulated as required through a small number of instructions. Now that we have distributed generation of which the majority is made up of renewable sources delivering variable capacity dependent on the weather the challenges have become greater and more numerous.

Full details of the consultation and published responses can be accessed at

https://www.ofgem.gov.uk/publications-and-updates/creating-right-environment-demand-side-response

Please note, as part of the FALCON Project design, we limited the scope of the Commercial Technique trials to non-domestic properties with Half Hourly metered supplies.

3.3 Design Approach

There are already a number of operational DSR schemes within the UK that are not run by Distribution Networks. They help manage conditions such as system balancing and help participants avoid peak costs such as annual transmission charges. More information on these can be gained in the appendices section of the report.

In considering how the FALCON commercial trials would be designed it was necessary to be aware of how pre-existing DSR services operate but not to adopt their design as the purposes for which they are used is very different to the geographically sensitive constraints that are the primary purpose of DNOs. As a result the commercial trials did not attempt to copy or adapt the design of any other DSR programme and a fresh approach was adopted, where we were able to define an appropriate use case that offered the best possible likelihood of success, particularly as it was to be measured against several other alternative methods.

With several other existing and even more potential future user of DSR services across the industry, an important starting point was to understand how and why other programme operators wish to use this approach. Furthermore, it was necessary to detail where there may be conflicts or synergies between programmes to ensure that the design that would be proposed within FALCON would be workable as an enduring arrangement and not over simplified simply for the trials.

3.3.1 DSR – Market / Programme conflicts

An important learning outcome achieved during the Seasonal Generation Deployment project carried out previously by WPD was that outside of the trials environment, there are conflicts with participants' other priorities including participation in other DSR schemes.

A great deal of work has been commenced into looking at the flexibility of different load types and identify where latency can be leveraged as flexibility to be sold as DSR. As well as with generators having to consider the core purpose of their asset, particularly in the case of standby power, research has determined positive correlations between reliability and regular use of the asset. This is generally down to a number of factors that relate to having a comprehensive testing regime for intermittently used generation. As with the average diesel car, it is more likely to be in a 'ready' state if regularly used and serviced, than if left for prolonged periods of inactivity. With generators there are a number of aspects that can be argued to reflect a good quality test regime. Regular running 'on load' simulates actual usage and test all critical components, such as:

- Battery charge for engine start health;
- Engine and switchgear settings;
- Mechanical components;
- Fuel delivery and quality. (supports manufacturers' recommended fuel management strategy); and
- Identify any faults during 'non-critical' operation.

Despite the largely technical benefits of regular usage in conjunction with commercial opportunities, there has been little analysis into conflicts between different DSR/DSM programmes and their operational benefits, cost savings and revenue. Below are the typical programme operator requirement 'use cases' and aspects that could be determined to act as barriers to BaU (Business as Usual) operations.

FALCON is not the only, or even first LCNF trial to include DSR as a key aspect of their trials in attempt to establish whether it is functional enough to be considered a viable alternative to conventional or new engineering methods of network operation. Much of the learning achieved from these to date has been included within the FALCON commercial trials to avoid unnecessary duplication of basic testing and establish the more advanced challenges including comparative analysis of reliability and commercial impact in a BaU environment.

Details of the preceding trials that have been carried out with LCNF funding are included within the appendix section of the report.

3.3.2 The SO – (System Operator)

As outlined within section 22.4, there are several programmes operated by National Grid in its joint capacity as System and Transmission operator. For demand side participants, the SO service is most commonly the 'Balancing or Reserve Service' STOR, but an increasing number of sites either offer, or are considering the potential of Frequency and Footroom services as aggregators develop offerings to harness the potential of multiple smaller sites. It should also be noted that while National Grid currently only procure a very moderate proportion of their balancing capacity from demand side providers, they have publically stated their intent to grow this to a minimum of 50% by 2030.

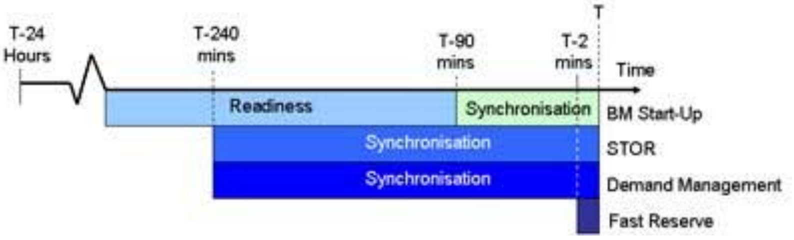


Figure 11 - System Balancing timeline

The diagram above which was sourced from the National Grid, 'reserve services' page (http://www2.nationalgrid.com/uk/services/balancing-services/reserve-services/) and shows how the range of services are used in relation to 'real-time' as represented by the letter 'T'. Demand side providers do not currently offer either BM Start-Up or Fast Reserve. For responses quicker than those offered by 'Reserve services', Frequency services are contracted by National Grid which can either be dynamic and constantly changing to reflect National System Frequency or triggered by at a specific set point with response times as rapid as less than 1 second.

The SO services of these types are on the most part contracted and dispatched on a non-geographic basis, but due to the criticality of the services, they are typically 'exclusive' and cannot be operated in conjunction with any other commercial programmes. A premium is paid for capacity by the SO in the form of an 'availability' payment and where appropriate a further 'utilisation' payment for volume delivered when called upon. Most significantly, the exclusive nature of the contracts means that if being paid availability payments for STOR, a site should not operate any other ancillary services or cost avoidance schemes that require the same capacity capability. This currently prevents multi-functionality from even multiple SO programmes simultaneously before even considering how this could be achieved by other markets such as Distribution Networks. It is however feasible that a site that can meet the technical requirements for Frequency Services can declare itself available for the faster response service during any periods where STOR availability hasn't been committed.

The SO does contract STOR services under two different contractual conditions, known as committed and flexible. As the name suggests, the flexible service conditions to allow for a limited amount of adjustability around availability, but under normal circumstances will still require to declare exclusivity for STOR provision on a week ahead basis. Such firm contractual conditions results in reserve services generally being in conflict with any other commercially driven operation during STOR availability windows.

In addition to the services listed above, National Grid has commenced auctions and contracting for further DSR through a new mechanism called 'Capacity Markets'. As this is not impacting the current DSR market until it goes operationally live. Further details on Capacity Market can be referenced inn Section 22.5.2

3.3.3 The TNO - (Transmission Network Operator)

National Grid also has the responsibility for Transmission Network Operation. Within the TNO's charging methodology for TNUoS (Transmission Network Use of System), it is possible to change consumption and/or generation behaviour to avoid annual costs for electricity transit through the transmission network. The commercial principles of this methodology are highlighted in section 22.4.1.

Triad avoidance is normally operated around one of two methods, Triad Management or Triad Warnings. Depending on which mechanism is used, the methods can be considered as DSR or DSM. This highlights an interesting anomaly within the overall service.

Most electricity suppliers can offer triad warnings to their clients which range in timing and frequency, from weekly through to daily, typically being issued either day ahead or in the morning for that specific day. There are also a small number of specialist energy management consultants who can offer a daily service based on either a success fee or annual subscription charge. These will typically be of greater accuracy as they will base their analysis on consideration of several supplier alerts, as well as their own internal working. When operating with warnings, a site is generally making the decision to operate in advance of real-time by enough time that it is more likely to be considered as DSM.

Reliability of ‘warning services’ for each source can partially be assessed by looking at their historical attainment for hitting all three triads, but also critically it is necessary to consider the number of warnings that they issued in order to achieve their performance record.

This, however, is only part of the picture as, due to changes in the way the overall energy market operates and responds to triad alerts, the changes can, and will, affect the reliability of warnings. There are three main factors that affect reliability and both are related to activity that takes place at the distributed level of the network:

- With an increasing volume of participation in triad avoidance, the warnings offered by the large suppliers have a direct impact on the likelihood of a triad being realised. Using the same principal as the combined impact of many consumers reducing their consumption, the increasing volume of participation will flatten many of the peaks. This results in increased numbers of calls requiring to be issued;
- As the winter period experiences a flattening of many of the peaks, it is also increasingly likely that the failure of any of the big suppliers to issue a warning will, as has historically been demonstrated, create enough of a peak to make that day one of the three triads. The consumers who subscribe exclusively to that particular suppliers Triad warnings will therefore also fail to hit all three triads.
- Increasing levels of distributed generation is connecting to the system at a Distribution level and is therefore not subject to TNUoS calculation. The most significant element of this is the rapid growth in renewables, in particular. If the wind output is either lower or higher than predicted it will have a direct impact on either increasing or reducing the volumes supplied through the transmission network. It is widely recognised that wind prediction is notoriously difficult and assessing how much may be delivered around a suspected triad peak, either several hours or days in advance, is a significant variable to consider amongst the other influences currently considered.

Triad Management is provided by aggregators by virtue of their technical infrastructure they have developed in order to meet response times and metering conditions set out by other schemes such as services from the SO. Due to their technical infrastructure, aggregators often have the capability to communicate directly on a machine to machine basis with assets on participating sites to either start / increase generation or reduce demand. This creates an advantage of not having to make a decision until closer to the time when a triad may or may not occur. During this time, aggregators may have the benefit of having received and assessed the impact of all the large supplier triad warnings in addition to those of any other subscriber services. They also have access to, and can monitor, the national system demand profiles that show consumption levels and generation outputs. These are updated on a 30 minute basis.

Armed with this more accurate information and the ability to remotely start / stop generation and reduce demand, aggregators can more prudently respond to ensure that all triads are avoided but have a risk profile that will avoid excessive number of calls and shorter runs, and thus reduce the costs associated with the operation. When operated in this dynamic manner, where notice periods are significantly shorter and potentially full responsibility for running reassigned to a third party, the operation of the service can be classified as DSR.

As avoidance simply requires a site to maximise their load reduction and increase generation in order to benefit, there can sometimes be correlation with other schemes which have a high propensity to be used during periods of high demand. This can sometimes result in the SO, TNO, supplier and DNO issuing a dispatch call during periods that eventually become classified as one of the three 'triad' periods, resulting in multiple benefits. This is, however, only a loose correlation and, if contracting to one of the other services, may force a site to reject triad warnings in favour of a previously contracted position. As triads are so lucrative it is common for sites to opt out of other programmes during afternoon / evenings of the winter period (November to February) to enable triad as the prime mover in DSM/DSR decisions.

3.3.4 Energy Suppliers

It is still not yet clear as to what form the Energy Suppliers impact will be on the provisions of I&C (Industrial and Commercial), DSR services. In many respects suppliers are already a major influence in DSM, and ToU variable tariffs can be a contributory factor in industrial and commercial processes.

Currently many I&C energy users will purchase energy on a flexible contract, or against an expected profile with an allowable variance. If the site therefore deviates significantly from their procured energy, by either consuming more or less than expected, it is feasible that their supplier can apply a penalty to reflect any imbalance in the supplier's trading regardless of whether or not the an actual penalty for imbalance occurred. It is therefore important that a site shifting or changing their total consumption or profile for DSM/DSR opportunities takes into consideration any negative costs that occur as a result.

Some energy suppliers already allow some of their larger and more sophisticated customers to take a more active role in self-balancing and trading and this is likely to grow in time. Out of this we can expect to see more bespoke and detailed conditions applied that will either restrict sites ability to work with other external programme providers. Or, potentially they will seek to develop their own aggregation capability to assume a more strategic role in the optimisation of participants' behaviour for commercial benefits to the parties who offer the greatest incentives, but minimise risk.

Where the I&C customer has flexibility within their processes, most likely by means of on-site generation, then we are also likely to see an increase in consumers entering into trading and arbitrage behaviours. This already occurs within a very small portion of businesses who have assets that enable them to achieve sufficient volumes to merit the relatively complex analysis. They have sufficient capacity to justify the additional risk that results from seeking to profit from adopting changing positions in relation to purchasing fuels, energy and then ensuring that final processes reflect this in real time.

More typically we find that the common role for an energy supplier in the current DSR market is as an energy purchaser, or ‘off-taker’ who purchases any exported power from a participant site through a PPA, (Power Purchase Agreement)

When large suppliers are approached to present a view of ‘if and how’ they expect to employ DSR within their future business operations it is typical not to receive a detailed explanation in response. This is to a large extent understandable, as they are independent commercial companies with responsibilities to their shareholders. It could be easily deemed as compromising to any business that is compelled to state what their strategy is towards the use of specific technologies. There are however a growing number of smaller suppliers who recognise that DSR can potentially bring added value and are openly seeking to promote their intention to commercialise. It is not expected that the large, vertically integrated suppliers with massive investment in generation are likely to adopt potentially ‘disruptive technologies’ quickly or as openly.

3.4 Summary and Conclusions

3.4.1 Performance against objectives

In many respects the trials were a great success in Season 1 (S1). The majority of the trials objectives were met including many significant developments for the industry and WPD alike. All key milestones were delivered on time and in accordance with the original plan for T5 and T6 as set out in the original LCNF bid and overall trials project plan. It must be acknowledged though, that there were several major challenges during each phase of the project from the initial design and build through to the operational phase where the majority of the empirical data was collected and allowed the range of learning objectives to be extended, resulting in the scope extension for Season 2(S2).

During the design build and (S1) operational phases the trial successfully delivered key objectives relating to commercial intervention techniques:

- Overall plan for commercial trials;
- Assessment of a DNO requirement within a BaU environment;
- Identification of a market structure and barriers to BaU operation;
- An appropriate cost justification model for DSR;
- Established a trial environment;
- Created a performance contract for DNO DSR;
- Developed back office software for performance monitoring and settlement;
- Engaged the entire UK Aggregator sector for participation;
- Recruited T6 target capacity, meeting all diversity criteria to satisfy trial learning objectives;
- Recruited a directly contracted T6 participant for comparison with third party service providers;

- Engaged with wider industry of Network and System Operators to address market barriers;
- Execution of multi-site, multi-event DSR operational trial;
- Research to capture of post event attitudinal data;
- Collection of granular site data for performance assessment;
- Operation of new back office software for programme administration and
- Completion of (S1) of T6 trials. On time and on budget.

There were a small number of outstanding areas where the trials did not achieve the desired objectives during (S1) which we attempted to address in (S2) as well as gain further data in order to complete all the original learning objectives that were proposed at the outset of Project FALCON:

- Acquisition of up to 1MW capacity for T5 load reduction trials;
- Operation of a functional Smart Meter solution for DSR;
- Improve DSR reliability rating for availability and utilisation and
- Network based monitoring to establish impact at 11kV and 33kV
- GAP analysis on DNO business to roll out DSR as a BaU service.

3.4.2 Added objectives for (S2)

The findings presented in the interim report, published June 2014 already led to several observations that progressed the DNO view of DSR to date. Some of these new factors disrupted the original plan for Project FALCON to carry out two years of identical trials in order that the research could be initially tested then validated in the subsequent winter's operation. In particular the understanding of the current market and its barriers were broached within a working group that was proposed by WPD before establishing sector wide support. Ultimately this was ratified through the ENFG, chaired by the ENA and attended by the UK DNO's and National Grid.

The Energy Networks Association (ENA) Electricity Demand Side Response Shared Services group was established to provide an electricity network operator (distribution, transmission and system) perspective of how DSR could be utilised by different parties. It set out a potential sharing framework under which the electricity network operators would be able to jointly access DSR resources. The framework focused on how network companies could maximise the DSR value chain within the price control periods for RIIO-T1 and RIIO- ED1, with particular emphasis on Distribution Network Operators (DNO) and National Electricity Transmission System Operator (NETSO). Further details regarding the findings and consultation published by the group are contained in section18.5.

The group developed a Shared Services Framework proposal that sought to address the conflicts between a DNO use case and the most commonly contracted balancing service STOR. This has a great deal of potential to enable participant to offer services to both a DNO and National Grid and we were therefore keen to incorporate a trial of some the main service requirements in (S2). The main principles that we were keen to test were

- week ahead notification of dispatch
- smart meter solution for site monitoring
- capped demand based DSR targets
- enhanced payments for load reduction

Details of the WPD project change request and altered scope and objectives are listed in section 20 of the main report.

The week ahead notifications were necessary to comply with the findings of the shared services group but it was hoped that it may also assist with a much needed improvement in the reliability of DSR for DNO use cases. Based upon the (S1) reliability statistics, it would be very difficult to offer a recommendation to use commercial intervention techniques as a long term alternative to engineering based methods. There is however a growing case to use DSR as a shorter term solution to manage potential or transient constraint issues by operational methods rather than engineering upgrades to the network. This could be particularly applicable where the investment case is not yet clear and the DNO is yet to identify capital spend as part of their well justified long term development plan.

3.4.3 Understanding the 'Use Case' based on results

From a DNO perspective, one of the major benefits for a service based method of managing a constraint issue through commercial techniques means that it will typically only incur costs to the business when it is being used. As a result it is far less likely to be in a situation where a large capital spend is necessary, but the extra capacity that it adds is underutilised. A good example of this is where a DNO makes an investment decision to upgrade network capacity at a substation based on annual consumption data clearly showing a steady rise in load which is assumed to continue to the point the existing infrastructure becomes overloaded. However, without the benefit of going and speaking with the main customer being fed off of the substation the network planners are not aware that the customer site in question is not just growing in load, but physical footprint and as a result they expect to move premises within the next few years. The result being that shortly after the upgrades to the network take place, the customer moves elsewhere and leaves the recent investment as stranded and under-utilised assets. Under such circumstances, if the DNO was aware of the temporary nature of the peak load requirement it may well have been the case that a DSR programme would have been quicker, more economic and less disruptive alternative. It may even be the case that the peak load never reaches critical levels requiring further action to be taken, and in those circumstances the whole initiative would cost no more than the nominal expenditure associated with initial set up of the contracts and any ancillary equipment such as metering.

It is expected that if DSR arrangements were to be used more extensively where future projections of load may cause brief or intermittent overloading on the network then it would not only be the short to mid-term solution, but also the trigger for investment reviews. By putting DSR contracts in place the DNO would require to talk with the customers connected to the potentially constrained network, this would in turn help provide intelligence that would help educate planners on the sensitivities that may affect their projected load models. Thereafter the DSR would provide a solution that would mitigate the need to reinforce the network ahead of need. If the DSR service was then utilised it could trigger an investment review to reassess the network and determine whether the case for capital investment has been made or whether any constraints are still going to be a rare incident, best managed through commercial arrangements. This would create an opportunity to re-run the SIM and establish what would be the best method. The SIM would then be used to establish whether commercial techniques remain part of an optimal solution or whether a combination of any of the five other techniques modelled within FALCON are more favourable:

- Conventional Reinforcement;
- Dynamic Asset Rating;
- Automatic Load Transfer;
- Meshed Networks
- Energy Storage.

This type of commercial arrangement is expected to work well with the planning of Distribution Networks of the future as the modelling of expected load conditions continue to become more challenging. With the changing use of electricity as highlighted in the early sections of the document, we expect to see increased volatility in the electricity demand profiles, as outlined in the table below. There are many factors that can, and will, interfere with making longer term predictions of what the future load characteristics will be on specific parts of the network

Influence	Impact
Electrification of transportation	↑
Electrification of heating	↑
Energy Efficiency measures	↓
ToU Tariffs	↔
Businesses moves premises	↓
Businesses growth / expansion	↑
Embedded generation	↓
Government policy / incentives	↕
Domestic Smart Meters	↓
General growth in domestic consumer electrical goods	↑

KEY	
Increase demand	↑
Decrease demand	↓
Shift demand	↔

KEY	
Conflicting impacts	↕

The impact of these various factors can start to take effect in concentrated pockets within the network over relatively short periods of time, depending on incentives and uptake of certain technologies. This has already been the case to date with reverse power flows and thermal constraints resulting from deployment of solar and wind generation by large developers or promotions focussed on uptake within specific communities. However it is feasible, particularly in domestic environments that a sudden uptake of heat pumps or electric vehicles could occur over the coming decade. This would not necessarily result in a self-balanced system, but could in fact create higher peaks and deeper troughs in the daily demand profile if allowed to develop without controls or governance structures. For this and other reasons, it is vital that DNOs start to develop capabilities to that will enable them to start to forecast the likely profiles of demand and generation and be able to take some direct actions to assist in the efficient management. There are already some blunt instruments such as DUoS charging (see section 22.5.5) that in theory allow each DNO to set an appropriate price signal to encourage customer behaviours. This unfortunately is still aligned with a centralised system where almost all connections are to consumers and the costs are calculated on the assumption of centralised generation supplies. This has become rapidly outdated in recent years as a result of the growth in distributed generation much of which is subject to weather and time of year.

DUoS and GDUoS rates are set annually and broke down by DNO franchise area, without the ability to separate into smaller regions or individual seasons. We can therefore increasingly find that often the payment or charge being applied is for much of the time in conflict with the demands being placed upon the network. For example, solar generation will for the most part receive additional payment through GDUoS during summer afternoons and early evenings, when in fact it is likely to be creating a problem. There are many cases where the DNO is likely to have to make very large capital investments to reinforce in order to be able to move the energy many miles to feed distant consumers. It may be that a restructuring of DUoS / GDUoS should be proposed to allow increased granularity of locational effect as well as being able to reflect time of day and year would assist the management of the network. However this is likely to take time and be subject to lengthy consultation processes and red tape. Therefore the ability to develop systems in line with the immediate needs of DNOs to influence or control behaviour is becoming a very attractive proposition.

3.4.4 Technical outcomes

While the trials were largely focussed on the impact of commercial techniques to manage network constraints, there were inevitably some technical aspects to the trials

- Metering
- Dispatch
- Forecasting

- Performance Monitoring
- Financial settlement / Billing
- Asset reliability
- In several instances the changes from (S1) to (S2) meant we obtained a wider set of results than we had initially set out to achieve. One area where this was particularly obvious was within the metering arrangements.

3.4.5 Metering

The (S1) metering largely adopted existing metering arrangements from customer own equipment, which included aggregator provided metering and output metering from the generator control systems. This was viable as we were only requiring to measure a delta shift in output or consumption at the point of impact on the customer site. This resulted in a range of different file formats and sometimes variable quality of data being provided. In many instances it was necessary for the site or their aggregator to manually extract or manipulate data from the default output file into another that would be compatible with the back office systems we developed for performance assessment and financial settlement. In a worst case scenario this could be open to abuse, allowing a participant to adjust the file and therefore the readings and it would be very difficult to detect. This is merely an observation and under no circumstances is there any suggestion that there may have been incidents during (S1).

The move in (S2) to a consumption cap necessitated a change of metering solution in order that the site could be measured at the point of connection. For this reason we adopted an alternative design where a smart meter capable of 1 min reading intervals was installed in series with the sites existing half hourly settlement meter. This had been pre-tested in laboratory conditions by WPD Smart Metering team and the result was a smooth roll-out without any issues to report. The data collection was based upon existing procedures for conventional remote meter reading and the data supplied the following day to a secure environment within WPD’s IT. Due to the standardised meter type and pre-configuration before installation, there were no data integrity issues where the software encountered corrupt or incomplete files that had presented problems during (S1).

It is expected that for DNO purposes a demand cap is likely to be the more appropriate method of targeting and monitoring participants as the use case relates more appropriately to geographical constraints. This is very different from National System balancing DSR services that are non-geographic and as a result can be measured at the point of generation. When it comes to ‘non-geographic service requirements, the programme operator is typically not concerned about the point of entry or exit for electricity in and out of the system, merely that both aspects are kept in balance with each other. It is therefore recommended that DNOs do not adopt the metering standards from non-geographic services but instead specify metering that is compatible with measuring an overall capping of site demand.

3.4.6 Service Dispatch

The FALCON trial did not attempt to create a direct interface to customer sites via a machine to machine or automated dispatch methods. It was not deemed necessary to duplicate capability that already exists within the DSR industry and other asset automation trials. The ability to communicate directly with assets on customer sites and even monitor their performance in real time would have been an unnecessary expense within the scope of the learning we hoped to achieve.

It has been proven that this can be achieved through a variety of different devices and over a wide range of communication types. It was also unnecessary to invest in the integration of the dispatch capability within existing control room systems as the trials would not be seeking to manage any live constraints within the trial zone. Even within the remit to provide DSR services within BaU it is entirely feasible that limited programmes could be facilitated without the necessity for complex M2M. This is reflected in the trials results which achieved acceptable levels of reliability in (S2) without the benefit of automation. This is largely down to the unprecedented notice period of 5-12 days' notice of events. The combination of generous notice periods coupled with the expectation of low event volumes means that more complex arrangement are potentially a bad investment. It would however be recommended that annual briefings take place with participants. This could be direct or via an aggregator with a view to ensuring that sites remain familiar with their responsibilities and DSR processes. This could potentially include an annual test event prior to any particular season in which there is an increased expectation or use.

3.4.7 Forecasting

With 7 -12 day event notification periods within the (S2) period of the operational trials there was an added requirement to test forecasting of event requirements in parallel. This would allow the principles of the 'Shared Services Framework' to be pursued if a successful outcome were to be achieved.

Currently DNOs do not do this type of operational forecasting other than for the potential of serious weather events that may damage the infrastructure and require additional engineering resources to be available 'on-call'. Typically the core of DNO forecasting is demand profile trends over a number of years in order to assess the areas of network that are likely to require further investment.

Using primarily weather data, National Grid's National Demand forecasts and some historical consumption data the trials lead attempted to identify the period of peak load on the network. These required to be condensed down to individual days and periods of up to two hours during any given day. The general results were very positive and a clear improvement in this could be achieved from the data collected during the trial being used to support future methods. There was parallel activity that took place within the trial to help determine the relationship between local demand and national peaks. It was noted that in doing so the FALCON DSR event dispatches managed to accord with two of the three National demand peaks on which the annual TNUoS charges are calculated, despite setting the dispatch notifications at least a week ahead. The level of correlation between local and national conditions was however not as closely matched as had been expected and a for the majority of the DSR events the local peak occurred earlier than nationally. Further research work will be required in order to test this further to gain a more detailed understanding of the factors that help influence the results.

- Commercial vs Domestic demand
- Geography
- Triad, DUoS and time of use tariff impacts

3.4.8 Performance monitoring

The performance monitoring of the sites that was developed for the trials was adequate for that purpose. It would be expected that if this was to be implemented in a BaU environments then there would be a single directing factor that would determine whether a similar high level design would still be suited. If there were multiple sites participating in the load reduction and thereby sharing the risk of critical failure on the network due to DSR reliability then it is feasible that performance monitoring could continue to be carried out post-event. In this scenario it is recognised the primary purpose is for ongoing statistical analysis of the constraint requirements and associated financial settlement. If however the risk profile was to be particularly reliant on a small number of sites or even that of a single DSR respondent it is likely that real-time monitoring would be necessary in order to ensure that there was sufficient visibility and notice within the control room to take alternative action ahead of the failure of a DSR participant leading to critical network issues affecting other customers.

3.4.9 Financial settlement / Billing

The financial billing and settlement aspect of the trials will be regarded as a great success despite the difficulties during (S1) resulting from the integrity of the data for input and in turn causing the settlements process fail its deadlines. However this was fully addressed within (S2) and the extensive revisions that were made to the interface and the manner in which the new standardised data would be processed.

Most importantly the trials set out an objective to design an appropriate payment model that could be authored in terms of algorithms that would underpin an accurate, automated system for financial settlement but also be simple enough to convey within a contract what the service delivery parameters would be for participants. This was in fact achieved twice as the change of scope for (S2) necessitated a full re-authoring of the underlying algorithms, which in turn received acknowledgement and praise during the post-trial stakeholder analysis.

3.4.10 DNO skills and resources – Gap Analysis

The technical challenges within the trials for the most part required to be addressed in order to enable them to function and be measured. This requirements was not as acute for much of the skills and resourcing due the operation of the Commercial Trials being outsourced to SGC who already have the majority of the knowledge and experience, but also the scale meant that it could all be done in isolation from WPD’s core operations. If however DSR were to be considered for use within a BaU environment there would need to be a whole new set of resources with the appropriate skills, processes and new tools in order to work efficiently. In this section we will highlight some of the key areas in which a DNO would require to develop its existing business and invest in its development personnel and systems. These have been separated into four topics

- Network requirements
- Engagement / Account management
- Operational intelligence
- Commercial Management

3.4.11 Network Requirements

The application of DSR is likely to be very different to more technical methods as these will most likely be capital funded works. It is important that a new set of assessment criteria are applied when determining where DSR is suitable for deployment. This is to a large extent the function of the SIM as to identify when it may be feasible but unlike other techniques it can be assumed to be available as it's not a unilateral service and require the identification and recruitment of suitable participants.

A DNO may in fact incur costs to try and identify participants and unsuccessful in recruiting adequate capacity. Under such circumstances it could be considered that DSR reliance on parties unknown at the stage of initial recommendations as a barrier to its implementation. It would therefore be worthwhile developing methods of contact and engagement with customers to educate and receive expressions of interest to start developing additional data for future use. Alternatively it may be the case that DSR arrangements are put into place to manage a forecast constraint issue, but rarely or never dispatched as the increased load peak never transpires. Under this scenario the savings over any capital funded technical solution will be extensive as well as avoiding stranded or underutilised assets.

An appropriate set of use cases and policies require to be developed in order to identify when DSR offers best value to manage short term or transient issues. It is also likely under such use cases, an annual review of the DSR arrangements will monitor the ongoing cost, requirements and if necessary trigger a review of technical alternatives.

3.4.12 Engagement / Account Management

Probably the area of greatest change necessary for the traditional DNO business and operations will relate to the engagement with stakeholders and participants. The traditional DNO business does have contact centres to manage inbound enquiries largely relating to faults and interruptions in supply. As DNOs operate licensed franchise areas where they are monopoly providers they have not had a necessity to develop a comprehensive team of public facing representatives other than for major account management customers such as property developers. By introducing services that require to be sold and relationships developed in order to manage the ongoing performance, contracting and customer communications. Where a new set of resources and a cost centre is created within the business it will then require management structures, human resources and accounting functions to support its activities. Many of these additional costs will add little cost to the overall operation of the business as it can be absorbed within the existing resources. There will be direct cost increases resulting from the new roles of ‘commercial representatives’ that will be able to contact, communicate and negotiate with potential DSR participants. These costs will then require to be shared across the range of successful DSR schemes and still demonstrate good value to customers.

3.4.13 Operational Intelligence

It is not currently the case that a DNO will do operational forecasting of the power flows and varying demands within the network unless it is to manage planned outages or ahead of adverse weather conditions that have potential of causing disruption. As the networks become more volatile, with higher peaks, reverse power flows and smart solutions such as DSR to manage them, operational intelligence will become increasingly vital as it becomes increasingly expensive to build infinite capacity, passive networks. Changing conditions will demand an active energy management function that will assess conditions and affect network operations as would traditionally be the case with national system operator. This may in time develop to a point where the GB system is operated in a distributed structure where DSOs will inherit the responsibility to balance and operate local markets. The initial steps towards this are likely to be focussed on the economic operation of constrained networks through active management, to extract the maximum value out of the networks assets.

3.4.14 Commercial Management

Over and above the requirement to engage with customers, operate the services and provide the business processes support, it should also be acknowledged that there will be further strategic development of DSR and other associated smart services at a market level. It would be advisable for DNOs to ensure that an understanding and influence of factors that may impact the economics or availability of services through appointment of role that is responsible for the ongoing development of the DSR market in keeping with the DNO use cases and innovate to ensure that best value is maintained for customers.

SECTION 4

Scenario Investment Model

4.1 Executive Summary

The FALCON Project has delivered a proof of concept (pilot) version of the Scenario Investment Model (SIM) software tool and used it for modelling a number of network evolution scenarios in the network trials area in Milton Keynes. As a result of the network modelling activity we have been able to draw a number of preliminary conclusions about network evolution in the town and its surrounding area as well as gauging a number of different strategies for handling network overloads as these occurred in the modelled scenarios and assessing the theoretical implementation of intervention techniques involved in field trials.

The project achieved the following main objectives:

- A derived consolidated database of network definition parameters (the Authorised Network Model) was compiled. This was created in a repeatable format from multiple operational sources and presented to the SIM to allow it to obtain a substantially complete and accurate detailed 11kV distribution network model at the nodal level which was capable of supporting the type of modelling required by the SIM;
- The project identified a number of limitations in the available network data, some of which derived from shortcomings in the sources. Based on this, indications as to future data requirements for the support of smart grid operations were sought and are presented in line with the project learning objectives in this area;
- Detailed results were obtained from real-world network trials covering the same network area and these were used to inform the SIM modelling activity. These were either adjusted to incorporate a series of suggested enhancements into the SIM modelling algorithms in order to improve their accuracy, or else future adjustments were outlined for possible later inclusion in the system;
- The project explored how to handle the representation of costs of various actions and interventions in the SIM and made a number of observations concerning both this process and the nature of the data itself;
- A software engineering approach was derived for implementing the SIM as a network evolutionary modelling tool. There were a number of aspects to this, but the design and implementation of an innovative search space exploration algorithm, the adaptation of an existing Network Modelling Tool for use as a system kernel, execution optimisation and the means whereby complex and extensive results can be represented meaningfully to the users were key aspects with successful outcomes;
- A set of modelling scenarios were identified and supporting data was generated covering load evolution from which the SIM experiments, exploring network response to these scenarios, could then be carried out. These experiments were evaluated and compared to other reference models to draw a number of conclusions; and
- A potential strategy for the future development of the SIM has been determined.

The project was successful in these objectives but arrived at the final result somewhat later than expected due to an extended integration phase which therefore required the project to adapt in an agile fashion to these changed circumstances. The design and build was carried out mainly to plan though we did lose the opportunity to conduct a series of RAD development cycles initially intended to incorporate user feedback and enhancements into the system.

In summary, and as described in more detail throughout the rest of this final report document, at the end of FALCON the project concluded the following in respect of the main success measurement criteria for the SIM project, framed by answering the following questions which had been prepared early in the project lifecycle:

- **Does it work?** *Yes*
  - **Functionally.** SIM Experiment *RUNs generated outputs for a series of postulated scenarios from which there are significant conclusions that can be drawn about future operations.*
  - **Performance and reliability**. *After an extended integration the SIM worked reliably and on an acceptable timeframe given the limited size of the networks under consideration though the application is processor intensive and any future SIM version would require a considered host environment and careful optimisation. The production RUN environment required the deployment of multiple, though low cost, host machines allowing experiments to be conducted in parallel.*
  - **Extensibility** (i.e. ability to process other network areas, need for Authorised Network Model input and associated Load Profiles). *The SIM is concluded to be extensible but not without some consideration of the data volumes involved and the processing times. However thought needs to be given to how large an area the tool should be asked to analyse. For local planners the network area is very small (not really extending beyond consideration of a single feeder and certainly within the scope of a single primary substation), however for strategic users it will usually be larger – but how large? An extended dialogue is needed with the strategic users to answer this and other questions prior to any adoption of a potential future SIM version as a business planning tool.*
  - **User interaction**
    - **How sensitive are results to planning timeframe?** *This was investigated directly by SIM experiment. The timeframes, like the network areas, depend on the purpose the SIM is being used to fulfil – short term detailed planning or longer term strategic analysis.*
    - **What do users think of it?** The initial user assessment concluded that the tool in its current form requires significant improvement in a number of areas to become usable as a business tool. At present the SIM is really only usable by expert users and then with developer assistance. This situation could be readily addressed - effort was directed during the development more at obtaining accurate and timely RUNs rather than refining the ergonomic aspects of the tool overall. For an expert user however the SIM is already yielding valuable results.
- **Future enhancements and development strategy.** *Ways forward for the SIM have become clear as a result of the FALCON Project and some work has already begun on*

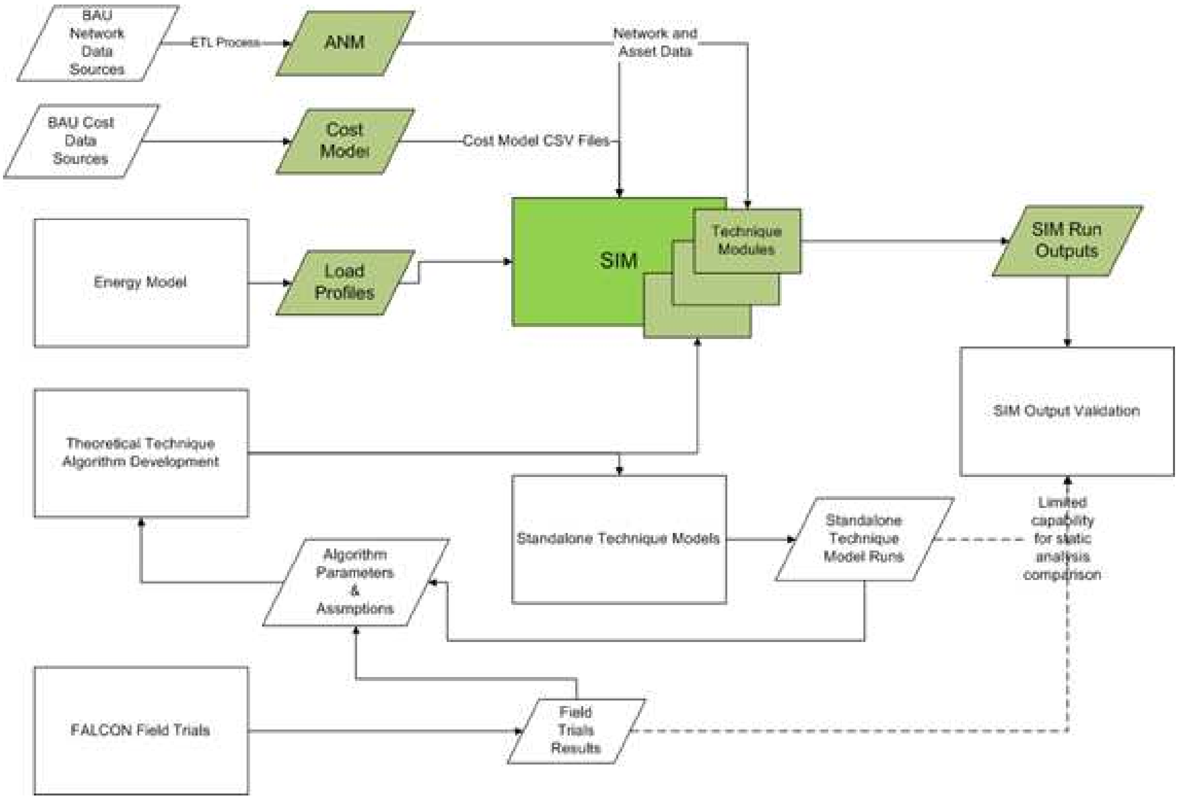
developments to support extension of the tool beyond the basic prototype. No firm decisions have yet been taken however in terms of where to take the SIM next.

4.2 Overview of the SIM

The diagram below shows the SIM in the overall FALCON project context. The major workstreams and data elements as well as the linkage between them are illustrated.

At the project outset, the high level objectives identified for the SIM were that it was to be used to find the most cost-effective way to run 11kV distribution network over periods of up to (around) 35 years, out to the year 2050, to explore the network response to a range of theoretical demand scenarios and investigate the result of deploying selected intervention techniques to address network overloads.

Figure 12: SIM Context



Source: FALCON Project

It was expected that using the SIM would make it possible to explore possibilities and then select the best approach to managing network constraints arising as load changes (in response to modelled customer behaviour and deployment of emerging technologies) given a range of technical and economic criteria. The project therefore set out to develop a software system and supporting infrastructure that would achieve these objectives.

The SIM identifies network constraints under multiple future network load scenarios and determines the most cost-effective and timely combination of remedial techniques to resolve them. To achieve this, the SIM utilises an enhanced version of the TNEI proprietary IPSA modelling product as its core Network Modelling Tool (NMT) component but conducts many iterations of analysis for different day types stepping forward through the years requested. The design requires a sufficiently accurate network topology dataset populated with appropriate electrical, thermal and other network component attributes. The actual dataset provided by FALCON for the SIM is termed the Authorised Network Model.

Matching against nodal points in the network are customer *loads*, these are implemented as Load Profiles, being arrays of load values arranged on a daily basis at 30 minute intervals (so that 48 load points make up a diurnal load profile for a given site and day type). The SIM evaluates the network against the loads on an annual basis, moving through the years specified in the evaluation interval and carrying out each new analysis using these evolving loads. A SIM "year" consists of just eighteen "*characteristic days*" which provide a pragmatic way to handle modelling of the intra-year time dimension as these cover the main types and extremes of load that would be expected to be encountered in a given year. Essentially, of the 365 days in a real year, most of these can be assigned to one of the 18 characteristic days. The SIM thus performs load flow analysis for the network for the 48 half-hourly periods during the day for different days of the week and different seasons of the year. Predicted load patterns generated from the Energy Model and imported into the SIM extend as far as 2050.

When the SIM is running an analysis and a voltage or thermal problem is found, the SIM selects from the supported remedial techniques that could help resolve the problem and determine how they could be applied to the network. The best solution can be selected using a weighted metric that combines elements such as installation, per use and operating costs, network performance, losses and disruption to customers. The SIM does this by conducting a guided search through the solution space and flagging failed or successful network states. Implicit in this is a guided search mechanism (A* Search has been chosen) and a costing model which provides an accurate means of assigning costs to the interventions carried out, as well as including the costs of regulator imposed penalties resulting from network failure conditions (CI/CML etc). These costs and penalties therefore feature in the analysis and the choices made, and are reported on an annual basis in the RESULTS.

The SIM therefore evaluates network response to a sequence of chosen experimental scenarios and looks at alternative paths to and consequences of resolution. It is thus intended in the first instance as a key FALCON objective to help direct strategic planning of future networks given a range of options about how the future will unfold out to a timeline of around 2050. The SIM also foresees for its BAU invocation a set of users, which includes a Network Planner, who will typically operate the SIM to plan future actions on the network based on load forecasting but on a much shorter timescale than that used by the Strategic Planner.

For the purposes of the FALCON SIM system development (including the trials that inform it) it was necessary to choose a set of initial remedial techniques, and these were built into the development.

4.3 Key Conclusions

4.3.1 Implementation of SIM Software System

The SIM consists of a Network Modelling Tool within a Simulation Harness with a middleware wrapper layer for data exchange between the two components. These worked together to allow experiments to be set up, executed and visualised using a Linux server and Windows client environments.

Very large volumes of input data were used with the network nodal model including six primaries but other network beyond the normal open points for those primaries outside of the core area. The resulting network model includes over a thousand distribution substations, with large volumes of accompanying load data for 36 years at half hourly resolution. Output data was no less significant and a file based data exchange mechanism was developed to avoid memory problems.

Automated testing was applied to the browser based GUI with integration testing building up through increasing levels of integration and complexity. This stage was highly iterative with many cycles of regression testing reflecting upgrades to software that came from new versions of the core product as well as bug fixing upgrades.

The project deployed a level of automated testing to ease the early stages of integration on the project. This included some GUI test automation tools. Integration testing followed more classic profile of assembling increasingly more complex component sets and testing these, though the SIMs own complexity levels leant themselves well to conducting tests at ever more increasing levels of integration. The path followed was incremental and iterative (repeating stages as necessary as bugs were found and cleared to ensure regression testing was carried out effectively) and included these main outline stages:

- To speed up testing an approach was taken to try to limit the elapsed SIM execution times by using a subset if the characteristic days. Reducing the half hourly periods used within the days was proposed but was not viable due to the technique processing dependencies.
- The design of existing Network Modelling Tools includes functionality to support constant user interaction which is not required for SIM usage. Similarly the current use of NMTs does not require the high level of robust performance necessary for the SIM. Reducing processing time supporting unused functionality and increasing the reliability of the NMT software would increase performance of the SIM.
- It was difficult to fully scope the work required at the start of the project before the design phase had determined the required functionality of the SIM. This resulted in some changes to responsibilities for functional elements. Despite having written interface specifications, this remained the most problematic area of the development.

- While collaborative working tools such as Bitbucket provided a good means to document issues, it was not necessarily the best means to achieve speedy resolution. The distance between the separate teams working in Manchester and Milton Keynes may have reduced the face-to-face working time. Combined working sessions and phone calls were seen to be more effective at resolving misunderstandings than written communications.
- Processes for code version control and deployment worked well, but the processes to provided data to the SIM such as load data, Authorised Network Model and Cost model information, while suitable to support a prototype, would require improvement for a production system.
- Performance is a key issue with the prototype taking considerable time to run an Experiment.
- While performance has been improved, the system would need further improvements to support use within the business. With several options for improving performance, this may be achievable.

4.3.2 Implementation of Nodal Modelling for Distribution Network

2. The future SIM requires an energy model that is scalable across a whole DNO region. This could be achieved by considering alternative sources for data to populate demographic attributes. Obtaining postcode level data rather than property level data may provide an acceptable trade-off between cost and accuracy. Alternatively, subject to smart meter data aggregating rules, it may be possible to use smart metering data to identify customer archetypes from which occupancy and demographic data can be derived.
3. Performance could be improved by restricting the day types, limiting the variations in each technique application, adjusting the thresholds for issues.
4. Reporting requirements have changed for the ED1 price control period and so the sourcing of cost model data will need to be revisited. The prototype Excel tool requires further development, for example by developing a more fully integrated data management GUI, if it is to be used as a production tool. Sourcing data for new techniques, not covered by BAU reporting, remains an issue though the pool of completed innovation projects that may provide reference data is increasing over time.
5. The size of the network model required to model the core six primaries within Milton Keynes is considerably higher than the core itself. In this case the total network required was three times the volume of the area of interest. This impacts on estimates for data volumes and number of busbars for the modelling tool. Analysing primaries one at a time allowed for faster processing times but resulted in new reporting requirements. Reporting investment on a "per feeder", to enable overlaps to be understood and accounted for. While this involves greater post-run processing this is a benefit overall and the feeder level data is likely to be useful to the business.

   Trials feedback was often difficult to incorporate due to the different nature of information used for real time operation and planning, or a specific instance to generalised application;

6. Data analysis (especially during integration and validation testing) required the development of inspection tools external to the SIM in order to facilitate validation of the results generated by the SIM. Some of the functions of these inspection tools might be usefully incorporated into a future SIM version, but for the moment remain as peripheral support facilities;
7. While the entire FALCON area contained a balance of urban and rural networks, there were fewer overhead lines associated with the SIM analysis area. This reduced the opportunities for the SIM to demonstrate the management of voltage issues associated with long overhead lines present in rural areas. It is likely that this could only have been addressed with a much larger network model that covered a larger number of primaries.
8. The volume of data needed to support the SIM operation is very large indeed and an approach to its management for real-time access was needed to be derived to prevent out of memory conditions on the host platform. Careful consideration to data management will be required for scaling up the prototypes.

4.3.2.1 Further Techniques

The SIM currently implements seven techniques and these have been evaluated by the FALCON project (or in the case of traditional reinforcement, this is known from standard BAU processes). In terms of other new techniques, it is recommended that these should be drawn from projects where real world trials have already been carried out and cost data is available. Results from the analysis to date suggest that it would be useful to extend those that can be used to manage voltage issues, though to model these correctly may require the extension of the nodal network model to include LV and/or primary network.

1. If the SIM is considered to be fundamentally a tool for advanced optimisation based on nodal model analysis there is no reason to limit the SIM to only consider load related reinforcement techniques. So, for example, the SIM could be enhanced to include switchgear replacement techniques, asset health indices and their associated fault probabilities and costs. By setting limits in terms of risk that encompass both risk of fault and the impact on the network of a fault in a particular location a reliability centred asset replacement programme could be developed. This could be optimised independently of the load related investment programme or the two areas of work could be considered together.
2. Techniques for losses reduction or network improvement could be modelled and optimised in the same way.

4.3.2.2 Future Adjustments Required in the NMT / NDM

There is a link between the performance of the SIM and the appropriate data handling. If concurrent analysis of larger sections of network is made practical by other performance improvements then this impacts on the data handling components which will then need to be scaled up. If the network will be analysed as a series of primaries then this suggests a different data handling approach needs to be developed to support that. Sensitivity analysis to the scale of the network area assessed is planned and will inform whether it is better to have fewer Experiments covering larger areas which take longer to complete or a larger number of Experiments covering smaller areas which complete faster and more reliably.

The existing Milton Keynes network as imported into IPSA has around 7000 busbars and is therefore within the limits of the current NMT which is set to handle over 20000. Scaling up the Milton Keynes network to cover all the East Midlands region, or all of WPD's operating areas would be beyond the current limit as it would represent a network with hundreds of thousands of busbars. While it may be possible to increase the limit on the number of busbars, from testing within the project, this would slow down the time taken to open windows, load and navigate network diagrams etc. to a level that would be unacceptable. As an alternative, it may be possible to create a set of network models for the user to select from that represent logical primary groupings for planning purposes. This would require the selection mechanism for network (the Network Data Manager) to have enhanced filtering facilities and a more complex mechanism to handle updates to assets in multiple network models.

Technique Data Inputs

- The DAR algorithm requires environmental inputs. In the SIM expected average values were used for weather variables and generic assumptions were made for soil parameters. For assessing DAR in real time there would be benefit in improving the data to allow more locationally specific values for soil conductivity. This reflects soil type but also moisture content which itself depends on recent rainfall, typical water table height etc. WPD's soil data obtained to support earthing calculations is not suitable for this purpose, but other aspects such as whether cables are ducted can be derived from the GIS data.

4.4 Authorised Network Model

The Authorised Network Model was successful in combining the asset and connectivity data from diverse sources to provide a unified network model for the SIM. This was achieved within the required timescales, budget and quality criteria. The approach used could readily be industrialised and scaled up to entire DNO regions and/or other voltage levels to provide high-quality modelling data and Common Information Model (CIM) interoperability. As the Authorised Network Model also supports a degree of data quality validation and mismatch resolution this is would also provide a good platform on which to base a Master Data Management solution for Network data.

Several additional datasets will be needed for Smart Grids, and these will also need to be appropriately managed and maintained within the overall Data Architecture. A better understanding of which data items the relevant modelling techniques are most sensitive to errors in is needed to identify which data aspects are worth investing in improvements to. Further research into this area would be valuable.

A two stage process is currently required to convert the WPD network data from corporate databases and systems such as PowerOn Fusion to the IPSA NMT file format. This requires importing data to an intermediate staging database (The Access version of the Authorised Network Model) followed by a Python scripted conversion to the IPSA i2f (internal network representation) format.

Some parts of this process would require to be automated in order to better handle the larger data sets associated with the full DNO distribution network. This may include combining both stages into a single process and providing a mechanism to process only the data changes made since the last conversion.

A different network storage mechanism may be implemented for the SIM Network Data Manager (NDM) and NMT based on storing the network data in a database format instead of the text based i2f format. This would reduce the complexity of the conversion steps and the potential errors that they introduce. This would allow the NDM and the NMT to read network data and directly from the staging database or similar.

4.5 SIM Results Analysis

For more detail refer to the FALCON SIM Workstream Final Report document.

1. The SIM has successfully integrated a network modelling tool within a simulation harness with a complex exchange of data. The network modelling tool has been enhanced to extend power flow analysis from a single point in time to 48 half hourly periods over 18 representative day types for up to 36 years of analysis at the same time as incorporating new functionality to estimate the CMLs and CIs for the network in addition to the usual power flow analysis to determine voltages, current, losses and fault level. New modules have been included that allow for techniques to be applied to the network that involve determining appropriate locations, validating that the technique is beneficial and creating a patch so that the changes are incorporated in the network model.
2. The optimising process has been seen to operate correctly and has been extended beyond the initial A* functionality to include a learning element which improves performance through feedback.

   Effective tools for visualisation, bug tracing and reporting have been developed to complement the main GUI.

   The prototype SIM has been able to demonstrate a degree of complex data handling that exceeds the previous use of network modelling tools as an embedded component. Therefore it is not unexpected that there are some remaining issues.

The main benefits of the SIM for the Planning Engineer would be the provision of a Power System Analysis (PSA) tool that comes complete with the 11kV Authorised Network Model already loaded and which would also give the planning engineer the ability to confirm the longevity of the design solution he/she has chosen for a new load connection by evaluating the network over time and with a number of alternative strategies and scenarios prevailing. At present much time and effort is consumed by the planning engineers obtaining accurate and complete network information for the area under consideration, perhaps as much as three times as much effort being expended in this direction than that actually spent in actually doing the analysis.

1. The 11kV Planning Engineers seldom look beyond a time horizon of five years, but even up to this sort of limit the SIM can still project the results of the planning actions over a number of possible scenarios providing a much more informed view of what is likely to happen next given the actions taken.
2. A key improvement to the prototype to assist 11kV planners would be to improve the user interface to provide an alternative to the geographic representation to make the connectivity and assets clearer. This would involve either replicating the existing schematic layout or creating a dynamic schematic representation that determines the optimum layout to represent the network selected. Such one-line diagrams are a feature of existing control systems.

The SIM could be used for strategic planning showing the longer term levels of load related reinforcement and the potential contribution from smart techniques. However further work is required to convert the prototype system into something that would be suitable for business adoption. These mainly relate to improving the speed at which the analysis can be completed but there is also some additional work to refine the calibration of load estimates to ensure these reflect the level of load reported by SCADA monitoring at feeder and primary level. Further work is required to determine the point at which the benefits of nodal network modelling (as opposed to more generic models) the additional processing no longer outweighs the additional processing overheads given the reducing confidence in both load and network data for later years.

The SIM has shown that traditional reinforcement techniques will account for the majority of network spend, but that the use of DAR and meshed networks will also be deployed to resolve network issues.

Thermal issues remain more prevalent in the medium term though some low voltage issues were observed after 2040 on some Runs. Large scale generation does not lend itself to modelling where prediction of likely size, type and location are required. Rather than complicate an already complex process further by repeated analysis to test different what-if analysis for large scale generation, another method needs to be developed to determine the impact of these connections on long term load related investment.

Batteries and Demand Side Management were seen to have relatively few applications due to the current price for batteries and the uncertainty around DSM availability. Sensitivity analysis to these factors and others is planned.

The inclusion of smart techniques has the effect of reducing CAPEX while increasing OPEX. A net benefit is seen in TOTEX of approximately 20% (subject to further validation) with improvements to network performance resulting from the adoption of meshed networks. Losses were seen to increase over the period due to network loads that increased over the period, with the peak load increasing by over 90% for some scenarios.

SECTION 5

Telecommunications

This section is a shortened version of the detailed Telecommunication Workstream Final Report which can be found here:

http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Telcos.aspx

5.1 Executive Summary

This section describes the telecommunications workstream of the FALCON Project and in particular presents a summary of the learning which has resulted from the design, rollout and subsequent operational activities. It is intended that the FALCON Project will inform the development of the future WPD telecommunications strategy as well as gathering the learning associated with the rollout and use of new communications technologies for the benefit of the wider utilities industry given that a number of elements in the FALCON communications system have been deployed for the first time in the UK and therefore presented significant learning opportunities. Our findings across a range of areas and activities bear out this initial expectation.

The primary role of the FALCON communications network is to allow monitoring and where necessary control of the engineering intervention techniques which the project trialled, enabling accurate data to be gathered from the field for analysis and use by other FALCON workstreams. The telecommunications system also facilitates the gathering of the passive monitoring data from the Low Voltage Monitoring devices widely deployed on the trials network.

The system was operated successfully in support of the trials and proved stable in use once a number of individual installation issues had been resolved. The IP architecture was flexible and the bandwidth available for the transmission of data proved more than sufficient for the needs of the network. The project concludes that WiMAX has proved to be a suitable radio technology for the FALCON application, giving high levels of control to the DNO when compared to other alternative candidate solutions. Failures to connect substations in various circumstances have been understood and the reasons for, and solutions to these cases are presented in the Final Report for the Telecommunications workstream.

The WiMAX technology in use and in particular the operating frequencies were the subject of a specific dispensation from OFCOM and UK MoD to test the FALCON systems and the report includes a section from the JRC which discusses the future possibilities for further use of WiMAX frequencies in the UK.

WPD is currently exploring the potential to utilise the FALCON Telcos network and the experience gained during the project to test other technologies across the WPD area to determine the most suitable option for the future. Introduction and Overview

One of the major workstreams of the FALCON Project provided the design and deployment of a pilot for a radio based telecommunications infrastructure, the primary objective of which is to support the FALCON engineering trials area in Milton Keynes. Because of its experimental nature, a secondary objective for the project was to develop the basis of a ‘system blueprint’ through which to inform the industry in the event that a similar WiMAX radio based telecommunications infrastructure solution were to be rolled out elsewhere.

The FALCON Project itself deployed four technical engineering and two commercial intervention techniques, and combinations thereof, which were designed to resolve network constraints. Such techniques may be used as alternatives to the more conventional intervention approach of “Traditional Reinforcement” which simply uprates overloaded assets to obtain a resolution. Not only were these new techniques deployed as field trials, they were also modelled in a computer simulation of the same area of the 11KV distribution network (by the SIM project workstream of FALCON).

The six remedial intervention techniques are:

- Dynamic Asset Rating;
- Automated Load Transfer;
- Meshed networks;
- Energy Storage;
- Distributed Generation;
- Demand Side Management.

The field equipment supporting the four engineering techniques (the first four in the list above) utilise the new IP communications network to return monitored data to a control/oversight and data collection function, the commercial techniques do not require the same level of communications support.

5.1.1 The Current Communications Architecture

To date and prior to FALCON, connectivity to the large and primary substations operated by DNO's such as WPD has usually (though not always) been via UHF scanning radio. In this architecture, each substation communicates back to a local UHF tower using a send and receive pair of antennas. Each of these towers has a high-speed backhaul using a combination of kilostream, microwave and dedicated networks connecting back to data centres in WPD. The GE ENMAC DMS system (now known more properly as Power On Fusion or POF) is the heart of the control centre. This System communicates with a Remote Terminal Unit (RTU) in each of the large and primary substations, allowing for the monitoring and control of the high voltage electrical equipment. The POF system controls the dialogue with these substations, with each being polled on a typical ten second cycle.

More widely, the smaller secondary substations usually (to date) have had no communication capability. However in the limited number of locations where communications have been deployed, a GPRS modem or unlicenced UHF radio is used to allow communications from the POF systems to the RTU. This has most commonly been for monitoring, but in a few secondary substations switching operations can be performed.

Where present, the communications has tended to be one-way, in the form of monitoring rather than control, and although the use of automated switchgear is increasing it is mainly served using the same technology.

5.1.2 A Possible New Approach to Communications

Whilst the FALCON Project overall is not primarily focused on the communications network, which is largely a means to an end, it is nevertheless a vital part of the project as the technical intervention techniques all rely heavily on a secure and robust communication infrastructure in order to be evaluated fully by the project. Across the utility industry, a reliance on the communications network is inevitably becoming more of an imperative as the concept of the smart grid becomes reality. FALCON was therefore charged with investigating whether a WiMAX radio based system offers a viable means to implementing communications infrastructure to support the Smart Grid paradigm.

The key communications goals of the FALCON Project were identified as follows:

- The design and deployment of a secure and reliable communications infrastructure that provides connectivity to the nine primary substations and the 200 secondary substations identified in the FALCON trials area. The following were specific requirements for the telecommunications infrastructure implementation:
    a. The Communications network will transport both Monitoring and Control traffic for the FALCON intervention techniques;
    b. The Internet Protocol (IP) will be used across the WAN and all the intervention techniques will deploy Ethernet and IP enabled equipment (or interface capability);

   c. The FALCON Network will incorporate an Ethernet station bus but the process bus will be hardwired connections. This station bus will provide communications between the IEDs and RTU where appropriate;
   d. Once the new communications network has been proven, the existing monitoring and control in the primary substations and the secondary substations may be migrated (where already existing) from the UHF network on to the FALCON Network[7];
   e. For the Meshed network intervention technique a secondary goal of deploying Teleprotection over the FALCON communications network will be investigated;
   f. The communications infrastructure should primarily be on a private network that is in the control of WPD and their partners.
- To build a secure communications network for FALCON that does not compromise the security policy of WPD;
- To prepare a view of the communications system design so as to be able to provide material for a blueprint for how utilities might deploy a future communications infrastructure for the Smart operations.

5.1.3 Constraints on the FALCON WiMAX Deployment

The FALCON Project had a number of objectives, not solely associated with the electrical engineering aspects of the trials, and when assessing the success of the FALCON telecommunications network implementation it should be remembered that this was a pilot proof of concept activity taking place in a limited trials area.

The FALCON WiMAX based telecommunications system implementation was cost and time limited and the radio solution adopted for the project was therefore necessarily constrained by a number of early design decisions made to accommodate these constraints. This included limiting the project to the use of WPD owned property for the siting of radio towers and other support infrastructure, and minimising possible planning delays by operating within permitted development rights. The former constraint effectively limited the geographical position of the main backhaul antenna sites to WPD Primary substations large enough to accommodate them, while the latter limited the height of these antennas. In addition, many secondary substations are located in out of the way positions and to some extent are even hidden away from view where possible to make them less visually obtrusive. With WiMAX being a line of sight or near line of sight technology best served by a clear uncluttered view to the basestation, this ultimately led to there being a small number of locations within the trials area where coverage was so poor that they had to be abandoned from the trials or data gathering exercises. Unfortunately the difficulties coincided in several places with the locations of some of the more important secondary substations involved in the trials, so alternatives had to be sought and remedial action taken. The constraints are summarised below:

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[7] This is a long term requirement, not a FALCON objective as in most cases the existing comms at 11KV is piloting other trials.

- As noted above, the decision was taken to avoid third party involvement and costs where possible and deploy equipment solely to WPD real estate (primary substations for the main backbone infrastructure). This naturally limited the geographic spread of the radio coverage as the usual maximum reliable working range for the WiMAX system in normal use is around 2km in most circumstances;
- Only FALCON trials locations were chosen for communications equipment deployment. This was an entirely pragmatic approach adopted early in the project. There is however no reason why non-FALCON primary sites could not have been used for telecommunications backhaul infrastructure. This would have improved the reach and spread of the communications network;
- To avoid having to engage with and be delayed by the local council planning process it was decided to operate within the envelope of permitted development rights which permits towers of up to 15m height to be used without reference to planners. This of course limited the height and therefore reach of the antennas on the main base stations;
- The means of raising the antennas to the selected 15m height above ground was chosen to be standard wood poles. While this provided a quick and cheap solution with in-house experience in deployment, it did mean that any pole top maintenance work needing to be carried out thereafter required the use of a MEWP for access. In anticipation of the need to avoid such access being required to the pole top in all cases, the main power breakers for the pole head equipment were installed much lower down near the base of the pole (to which cables had to be run). These poles attracted little adverse comment from neighbours which might not have been the case with metal lattice towers had these been used instead;
- The project did not utilise some extant inter-primary fibre connections to form part of the connectivity which just happened to be available (linking Bradwell Abbey, Childs Way and Bletchley primaries) as this was considered to be counter to the investigative brief of the FALCON project and would have added little to the learning. The option was considered when connectivity options were being reviewed.

Because of the above, network coverage was somewhat limited from the outset and the project found that a number of secondary substation sites could either not be connected as a result or else had varying degrees of connection difficulties. This would not have been the case if the network had been organised to ensure connectivity based on previous learning rather than being constrained by time and cost. On the positive side for the project, this did mean that it was necessary to carry out a lot of investigative work to understand the situation on the ground for a number of problem cases. This approach led to the gathering of significant amounts of learning, presented in this report, which may be incorporated into adapting the approach for future deployments.

The FALCON Project required the rollout of monitoring and intervention equipment to around 200 electricity distribution substations. These were chosen from the subject trials area in Milton Keynes, an area containing around 800 secondary substations in total, and these sites were chosen early in the project without reference to their potential for radio coverage. The substation selection criteria was thus in the context of the wider

FALCON objectives and radio coverage was a secondary consideration to selecting the appropriate substations for the primary FALCON objectives.

The data traffic was envisaged and designed to include control as well as monitoring data, so speed (latency) was an important consideration in the telecoms design. The physical carrier was chosen to be based on a WiMAX radio solution. The 1.4 & 3.5 GHz frequencies are currently largely vacant and have been used by the MoD who are potentially relinquishing full control and reservation of these bands and had granted their use for the period of the FALCON Project on a temporary *Authority to Test* licence.

The project was also required to observe an operating constraint forbidding use of the 3.5GHz frequency during the British Grand-Prix at Silverstone as this was also being used for the event. We note here that going forward, should the frequency become available and taken up for utilities use, such restrictions would not be acceptable for BaU - but permissions may be granted on a case by case basis where it did not compromise the effectiveness of the DNO.

5.2 Approach to Knowledge Management

Learning was gathered through all phases of the Telecommunications system design, deployment and operations and documented as the information was obtained. The key learning target areas were captured very early on, in some detail in certain subjects, and a number of subject domains were identified in key areas, with information gathered as the project progressed. The details obtained for the learning points were noted at the same time as they arose in order to ensure that the information was as complete as possible, but a further ongoing source of information was a master site rollout management spreadsheet which was maintained from the very start of the site installations. This spreadsheet was organised by site and included the main site reference details as well as rollout notes which were mined for information in the later project phases.

5.3 Conclusions

As noted above, the FALCON WiMAX pilot rollout was time and budget constrained and so it is not fair to assess this solely against fully funded and deployed BAU solutions. The FALCON Project communications workstream, by its nature, took a route which flushed out a significant amount of learning which might not otherwise have been found and established a good working telecommunications system capable of supporting the FALCON trials. A solution having a more complete radio coverage pattern would certainly not have observed several of the issues that were seen in practice on FALCON. In this then, the FALCON Project has been a success in finding and documenting these items for consideration by others who may be thinking of a similar implementation.

This section presents the specific project conclusions and also makes a number of recommendations.

5.3.1 Specific Conclusions

Our observations of the behaviour of the WiMAX radio system are as follows:

- A good signal allowing reliable IP level communications with WiMAX based radio systems is best achieved with a clear line of sight – best examples of good connectivity were seen where the substation and base station were across an open valley from each other. Clearly this means that there is less clutter (buildings, trees, topological features) along the line of sight;
- With an open unhindered line of sight WiMAX can have a significant range (the project noted a usable link (RSSI -82bD) could be maintained between Moulsoe Church and Horwood at a range of 14.9KM);
- Where there is no clear, unobstructed line of sight between the substation and the base station the strategy must be to establish one. This will usually mean to gain height where possible and avoid obstructions such as buildings and/or trees. Given that the base station is likely to be fixed and in place early in the rollout, this means installing a high pole for the antenna mount at the substations;
- Further to the above points, the best signal for communications to the substations was not necessarily always established using the closest base station. Even distant base stations (at workable ranges of 5-7 km) with clear lines of sight sometimes proved a better connection option than a close base station (1-2km) having a poor line of site to the location under consideration;
- A strong radio signal, even with good signal to noise parameters, does not necessarily result in good communications at IP level. In particular the antenna bearing seems critical to achieving a good usable signal for the IP level;
- A radio signal which is too strong (better than -40 dBm) can also be a significant issue, as was seen in the primary site radio links implemented via CPE devices and for substations closer to the base station than around 400m. In such cases fitting of radio attenuation devices to obtain a signal somewhere around -55dBm was found to be very effective. Depointing the antennas was not effective – resulting in noisy signal (i.e. extended packet times and losses) at IP level.
- A reflection is not necessarily a good usable signal even in cases where the signal strength seems high. Reflected signals may suffer some degradation which makes them less usable though the evidence for this was limited and the cause is not clear (reflection polarisation perhaps);
- The project found evidence of poor reception in regions around very large buildings, not purely attributable to blocked lines of sight. Several substations in the environs of the MK Dons Stadium experienced difficult communications (ASDA Store, JJB Sports) where this would not normally be expected and the antennas had to be pointed off the nominal bearing to the local base station to obtain a usable signal. The same effect was seen in the area around the Milton Keynes *XScape Ski Dome* (another very large building) and the tall Stephenson House building in Bletchley. More in depth follow up investigation is recommended to determine more about the problem in

such cases, FALCON did not have the necessary expertise and equipment to do this within the Project scope;

- Radio interference is an issue. This was seen where multiple base stations were roughly aligned along the same line of sight both in the same direction but also in front and behind the substation in question;
- Where radio interference is present, the measured RSSI at the location suffering the interference may have a higher value than expected due to the additive effect of the interfering signals. This can be misleading, especially initially until the presence of interference has been established. Stronger signals are usually better, but with interference (especially if undetected) this may not necessarily be advantageous and a correct indication of the site status;
- Radio interference can be alleviated by the following means:
- Using attenuation. This may be applicable in situations where it is possible to take one of the interfering signals below some threshold;
- By re-aligning the antenna bearing – to point away from the less desirable signal or perhaps even to choose a totally different base station.
- For a misaligned antenna, the pickup off the back of an antenna pointing on a bearing 180° off the correct azimuth is around 20dB below the signal received from the front of the antenna;
- The project was only able to use 3 distinct WiMAX frequencies in the 1.4GHz band to be spread around the base stations so that adjacent cells were not operating on the same frequency and so reduce the chances of interference. The project saw several cases of interference however even over quite large distances of separation, and we conclude that a greater number of frequencies would thus have offered a far better solution less prone to interference;
- Key to solving radio issues in the FALCON WiMAX system (and it is expected to be more generally the case) was understanding the root cause of the problem. This Report provides details of the issues seen and in most cases resolved by the project, and this understanding process and knowledge should be useful for other projects in the future;
- With the modernisation of the electricity distribution grid, the complexity of power system installations will increase. New functions will be introduced and more devices integrated in order to achieve truly distributed intelligence. In parallel, many more interconnected systems will be rolled out and operated. This raises the bar for robust, extensive security architectures. Resilience and survivability are important quality attributes for mission critical installations. New technologies such as "behaviour based security", domain specific anomaly detection and device virtualisation need to get integrated. Networks, devices and security installations must react "intelligently" and be resilient to attacks in order to survive and keep our energy supply secure and stable while the designs are sensitive to enhancements such as closed loop tele-protection;

- It is sometimes very difficult to isolate a fault and be specific about where in the overall communications system its causes were located. This meant that once initial investigative work had been completed by the project it was necessary to involve specialist support from both Cisco and Airspan, sometimes with these parties acting cooperatively to resolve the matter;
- The project selected the Bradwell Abbey Bulk supply point/Primary as the central area network aggregation point terminating the onward microwave link to Horwood. This was done partly because of the availability of the tower at Bradwell Abbey giving extra height for the link. However not all the FALCON Primary sites could establish a usable 3.5GHz backhaul link to Bradwell Abbey and were connected instead directly to Horwood. A different choice of aggregation site in the central Milton Keynes area may therefore have been beneficial to the project;
- More base stations deployed around Milton Keynes on unobtrusive 15m wood poles would almost certainly have given a better 1.4GHz coverage capability to the FALCON network rather than deploying these to a limited number of WPD primaries involved directly with the FALCON trials;
- A typical round trip time latency for substations attached to the 3.5GHz backhaul of the FALCON FAN was measured at around 105ms in cases where there was no relay leg on the path. In cases with a single relay the RTT latency rose to around 125ms. For substations attached directly to the main aggregation points, the RTT latency was measured at around 73ms at the furthest downstream location (Horwood) and 85ms when attached to the microwave link (Bradwell Abbey). These findings confirm the metric from Airspan that each additional hop in the communications path adds an additional 20ms to the RTT latency;
- One obvious conclusion from the above would be to attach substations as close as possible to a network aggregation point, and to design for this to be realised, making best use of microwave and 3.5GHz WiMAX links.

5.3.2 Specific Recommendations

- Base stations should be installed with the highest possible antenna mountings in place early on. The minimum height which should be considered is 15m but more height will ensure less problems with secondary site connectivity later. Clearly local conditions need to be factored in to this basic recommendation;
- A cost/benefit analysis should be carried out before any future systems are deployed to consider the possibilities for the use of alternative base station hosting locations and to determine the best approach to the deployment of these;
- Because of the restrictions in the FALCON operating “test” licence, the project was obliged to operate without the 3.5GHz backhaul infrastructure element for one week in each year[8]. During this interval it was the case that sites connected to the main WPD spine network via microwave link (directly at Horwood radio tower and those

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[8] Silverstone British Grand Prix.

secondary sites connected to Bradwell Abbey) remained usable. This led us to conclude that backhaul infrastructure based on Microwave links would have been better for FALCON and could be considered in other cases;

- In cases where there may not be blanket radio coverage, when choosing where to locate sites (if this luxury is a possible option), installers should pay attention to both the communications capability at that location as well as to the suitability of the location in electrical distribution network terms. The communications capability should be validated where possible before any actual deployment to that location is made. This approach does require more initial planning but avoids the possibility of a later situation arising where a site (at which considerable investment may have been made) cannot be brought up on the network. This clearly does not apply for a full BAU rollout where coverage needs to be obtained wherever needed. The fact that some sites needed to be abandoned and replaced by others because of unsuitable radio coverage is a reflection of the fact that FALCON was a technology evaluation “pilot” project with a limited budget and timescale. For a full BAU rollout this situation should not arise if the various recommendations that have emerged from the project are followed;
- In a WiMAX radio network implementation ensure that the base station nodes which create the backhaul spine to the system are rolled out and brought online first. Then before any equipment is rolled out to any substations, conduct drive around tests to establish the coverage profile based at the deployment locations based on real world radio reception measurements. Additional base stations should be added as necessary to provide coverage for any blind spots and the network tuned. This therefore forces significant additional work early in the project, but it is believed that this will have the effect of significantly reducing difficulties with radio coverage later;
- Site rollouts, particularly for a large programme of work, should be meticulously planned, tracked and optimised so that the number of visits to each site are limited. Subcontractors could be incentivised with payment linked to completed activities (verified site deployments establishing that acceptable radio parameters are established). Teams could be encouraged to take ownership of their piece of work and pass sufficient coordination instructions to the following teams. Work directions should be documented, tested (proven) and repeatable;
- Our findings suggest that placement of certain communications equipment in close proximity to 132KV conductors can in some cases result in interference with the operation of this equipment (the particular example being the GPRS time synchronisation signals needed to operate the WiMAX TDM based system). It is therefore recommended that specific attention is directed at placing radio equipment away from such potential sources of interference;
- Any antennas mounted on long poles need to be cross braced to prevent excessive vibration to the antenna noted during even moderate breezes;
- Where a choice of the type of pole is possible for a small substation deployment (cranked vs straight) a straight pole is preferable as these allow for ready adjustment of the antenna bearing if this is required at a later time;

- Assess all WiMAX substation sites fully before installing any equipment there even to the extent of considering transitory factors such as parked delivery lorries in commercial locations. These may not be present when the assessment is done so there needs to be intelligent consideration of such additional possibilities;
- Implementers should avoid co-channel interference by pointing a secondary substation antenna close to the bearing of the required base station but away from the distant (not required – interfering) base station where these lines of sight are close to each other[9]. Thus align the antenna away from the non-required base station consistent with still receiving a good signal from the required one. An alternative may be to reduce the interfering signals by attenuation (on Falcon 10 dB and 20dB attenuators were fitted in different circumstances) such that one of these is reduced below a level where it is a problem. The project evidenced good results at one problem substation in particular;
- Even when the radio signal parameters show good values, the accuracy of the antenna bearing should still be verified as even a misaligned antenna can send/receive a seemingly good signal although this may be unusable at the IP level. This should be done anyway as a non-optimally pointed and tuned in substation node may step up its power to try to work and may thus cause problems for other attached substations on the same base station. Such tuning and optimisation should not be overlooked. In summary, a simple view of the radio parameters that indicate that a site is adjusted to an acceptable level, does not always mean that this will be the case at the IP level, and the quality of reflected and/or off-beam signals in the cases that we investigated has therefore found to be questionable for the communication purposes of the FALCON Project;
- When measuring or determining antenna bearings in substations, be aware of the presence of magnetic fields which can distort measurements using a magnetic compass. Disturbance may occur from transformers and underground/overhead cables and other magnetically noisy equipment such as motors and even (and powerfully at close range) mobile phones. Confirm results using multiple tools and then follow the approach of panning in the antenna to obtain the best radio signal giving usable IP level connectivity;
- Pay attention to the placement of radio equipment in substations near other organisations as there is potential for interference (in either direction). Even if not on the same operating frequency there can be harmonics and breakthrough at different frequencies where signal levels are particularly high;
- FALCON radio statistics analysis provided a simple diagnostic tool for identifying problem substations, particularly during rollout. The Project recommendation is to simply collect the radio statistics for a suitable interval (several days recommended) for all sites, average the RSSI (signal strength) and CINR (signal to noise) values, plot these, and concentrate investigation on those not falling on (or close to) the resulting

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[9] Noting that the alignment can be to the front of OR BEHIND the antenna in question (180° away from the main line of sight onto the back of the antenna)

line (for further details refer to the FALCON Telecommunications workstream Final Report). This can be found here: http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Telcos.aspx

- The FALCON Project diagnostic method for plotting average signal parameters (RSSI/CINR) for all substations could readily be packaged and used as a diagnostic tool forming part of any future radio installation process.
- When making adjustments in the field to antenna pointing and selection of the best signal to use at problem locations, a coordinated attack with support from central monitoring facilities is advantageous. Feeding back results and giving instructions to the engineers allows all monitoring capabilities to be leveraged to advantage as the tools available in the field are limited. Extended follow up monitoring is also recommended to be sure that the system was not just caught at a good time.

5.3.3 Reasons for Poor Radio Connectivity

One or more of the following were found in practice during FALCON installation and operations. In combination these issues proved very detrimental to reception:

- Poor location, fixed aspects:
    - In a dip/valley shaded from base station or behind a hill;
    - Line of sight to base station obscured by houses, buildings. Mitigate by choosing alternative base station if possible, and selection of where on the substation to locate the antenna for maximum clear view.
- Poor location, transitory aspects:
    - Line of sight to base station affected by foliage (trees, bushes etc.) especially deciduous varieties in the short range;
    - Line of sight sometimes obscured by parked vehicles (delivery lorries etc.) – mitigate by selecting base station in direction away from threat or taller antenna mount;
    - Line of sight becomes obscured by building works occurring after installation (may be unknown until the signal drops).
- Incidents:
    - Fire (Ashlands stadium) resulting in complete loss of substation. The fire was not FALCON related and was established to have been caused by vandalism;
    - Suspected knock to antenna from high sided lorry resulting in misalignment of antenna (Oxford St. Bletchley);
    - Vandalism (petty or severe) causing degradation through damage or misalignment of antennas. An example of petty vandalism: using the antenna for target practice (Moor Park Bletchley).
- Equipment issues:
    - WiMAX cards faulty;
    - Router faulty;

  - Cable joints/terminations not water proofed.
- Installation issues:
  - Best base station (where options exist) not chosen;
  - Antenna not high enough (see above re: hazards);
  - Antenna bearing not optimal (or even way off beam) may cause poor signal OR poor IP level communications even for apparently good signal levels;
  - Cabling not terminated correctly (bad jointing);
  - Selecting a poor quality reflection in preference to a weaker direct signal (basing decision making on radio stats only);
  - Omitted or poor quality weather proofing (sealant) etc.
- Other transitory effects:
  - Co-channel radio interference – line of sight taking in two or more base stations;
  - Weather events (wind blowing antennas/causing these to oscillate or move), heat (sun on unventilated housings causing items to overheat); rain (signal attenuation, especially when moisture is collected on immediate Line-of-Sight foliage).

5.3.4 Wider Application of WiMAX Technology for DNO Communications

It is a primary objective of the FALCON Project to make learning gathered in the course of the work done and from the execution of the trials themselves available to the wider industry. At the first level the question to be answered is whether WiMAX offers a suitable technology for use by utilities, and specifically DNOs, for implementing a reliable substation communications network.

This assessment clearly needs to be carried out against competing technologies.

There will always be pitfalls inherent in trying to extrapolate a small scale trial up to the sort of scales relevant to DNOs or similar organisations but clearly there are inputs from these trials which can usefully inform the decision making process. Some of the conclusions from the FALCON trials specific to the communications workstream are therefore listed here.

- A bespoke WiMAX radio based telecommunications system based on commercial components from Cisco and Airspan used to support the operations of an electricity smart grid has been deployed in Milton Keynes as part of the project FALCON implementation work. WiMAX has proved to be a suitable radio technology for this application yielding a low overall installation and operational cost solution while giving high levels of control to the DNO when compared to other alternative candidate solutions such as fixed line;
- WiMAX radio is implemented using AIRSPAN radio units coupled with ruggedized Cisco Router technology for the IP routing capability. This offers a resilient IP network solution for use by utilities and others where site access and installation may be an issue, and particularly for locations where there is no existing telecommunications infrastructure;

- A low latency solution may be implemented by minimising the number of routing node hops necessary to communicate with terminating equipment. Where additional hops are necessary in the link path due to coverage considerations, the solution still provided a low latency capability for the FALCON trials network and the same can be expected for other implementations. This allows a teleprotection scheme between secondary substations to be run over the WiMAX network;
- The use of half duplex communications on the radio links is not inconsistent with the typical network traffic consisting of mainly small SCADA data packets;
- Alternative bearings for any given site are highly likely to be available in a grid implementation of the type supported by the FALCON electricity distribution and matching telecommunications routing networks. This may result in more distant links and high gain antennas may be required to support such alternate routings where line-of-site issues exist (if directing a link towards a distant aggregation site, see next);
- Rather than implementing additional hops in most cases, on the FALCON Project, the radio coverage permitted the direct communication between the distant Horwood location and the primaries affected by line of sight issues to the closer aggregation site at Bradwell Abbey;
- The nature of the WiMAX radio solution for telecommunications support infrastructure for an electricity smart grid environment readily lends itself to adaptation and adjustment in the field should expected theoretical signal coverage not be realised. This is primarily due to the number of alternate relay locations that are likely to be present;
- The cost of the rugged WiMAX radio based solution for Project FALCON is modest when compared to the likely costs for an IP network infrastructure based on fixed line telecommunications. However the potential licence costs associated with extending the use of the WiMAX solution from test to full operations is not factored into this assessment as it is currently unknown;
- It would be advantageous to utilities and other critical national infrastructure organisations to have access to a WiMAX / 1.4GHz (or similar) frequency solution. We are working with the JRC to further explore the possibilities in this regard.

5.3.5 What Next for the FALCON WiMAX Network

WPD is considering what to do now with the FALCON trials equipment and telecommunications network and has options going through the bid process at the time of writing this Report. At least one follow-on possibility - the *Telecoms Templates* project, if accepted, is planned to cover deployment and checkout of the latest technology radio options for Low Carbon Smart Grid Networks. During the initial meetings it was identified that some of the existing Low Carbon network Infrastructure such as that put in place by FALCON would lend itself to the Telecoms Templates Project rather than being decommissioned, especially when it is recalled that these have already financed by Ofgem and WPD believes strongly that this would be a significant plus point in favour of this bid submission.

Potential use is unconfirmed for now, but possibly includes using the system for further Mesh Network roll out with Cisco and trialling other frequencies to test coverage abilities.

Some of the FALCON recommendations and summary points could also be considered for investigation, including, for example, the introduction of microwave links for backhaul as opposed to simply using the 3.5GHz Airspan links as at present.

Clearly ongoing use of the WiMAX frequencies would be dependent on the authorities granting further *Authority to Test* licences, and some conclusions are yet to emerge in this regard in terms of their future use within the utilities domain.

5.3.6 WiMAX Frequency Regulatory Policy and Future Plans

This section is contributed by the JRC.

Secure and resilient communications form the heart of a modern intelligent grid. Although significant communication paths are based on copper and optical fibre, radio is increasingly being used to provide communications, especially in the 'last mile' and where roll-out has to be achieved quickly and flexibly. But radio systems need access to scarce and valuable spectrum in which to operate. All radio spectrum is currently allocated to one user or another, in many cases government.

For the FALCON Project, a radio-based solution was required which provided medium speed data rates combined with medium distance reach and penetration through trees to enable the antennas to be located around ground height (2m) rather than above the tree canopy at 10m. Radio spectrum around 1400 MHz appeared ideal, but needed to be proved in this application.

The radio spectrum holder most amenable to permitting a trial project was the Ministry of Defence (MoD). Since the government has a programme of releasing publically held spectrum for commercial use, MoD were amenable to a trial in their spectrum at 1427-1452 MHz

MoD use this spectrum for a variety of confidential specialised applications, but usage around the UK varies, with the whole of their allocation thought to be used in only one location. MoD therefore agreed to a Limited duration trial.

Figure 13: WRC 2015 Options for 1.3 - 1.5GHz Bands

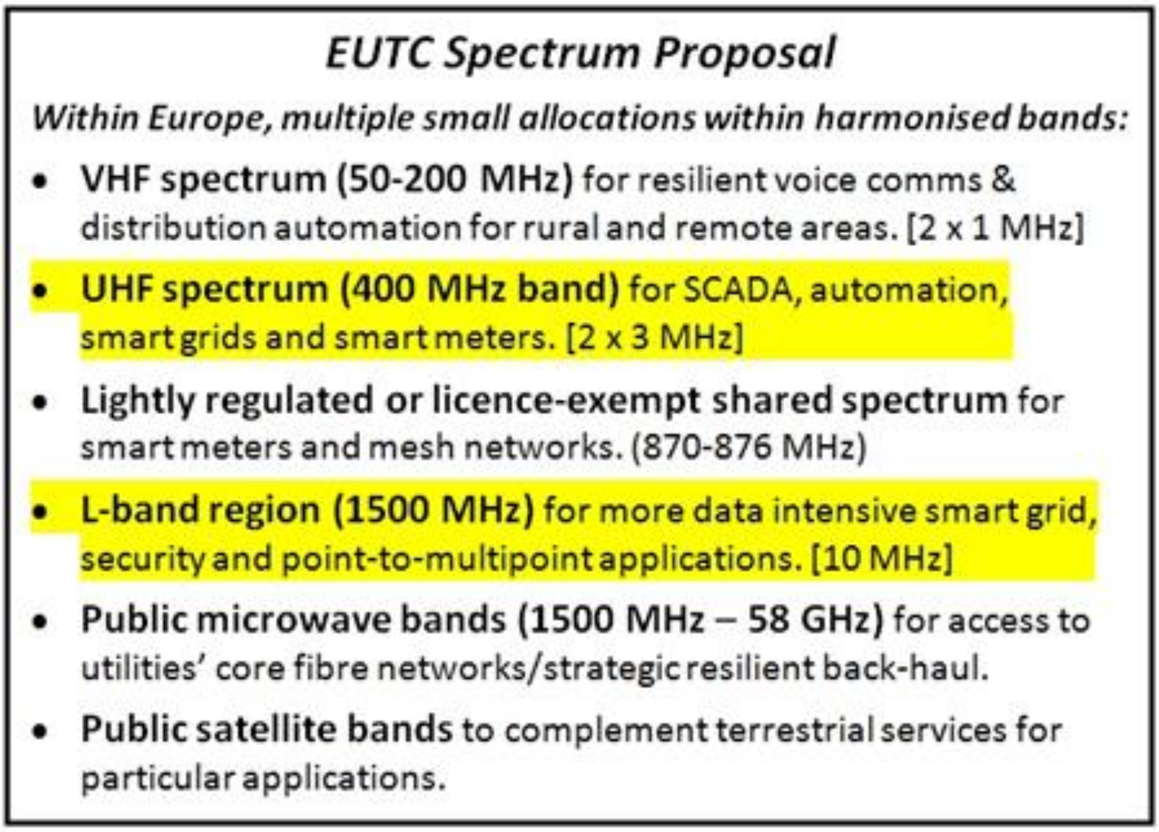
Source: JRC

The radio spectrum around 1400 MHz has disparate uses internationally, and is subject to revision at the forthcoming World Radio Conference in November 2015. It is not possible at present to be confident about future use. Although part of the band from 1452-1492 MHz has been re-allocated on a European basis to 'Supplementary DownLoad' for mobile devices, the part in which FALCON operates 1427-1452 MHz may be left untouched because of the disparate current use and ownership internationally. This might enable its continuing use for utility applications which can utilise spectrum not suitable for harmonised mobile data applications.

When the band 1452-1492 MHz was auctioned in 2008, it was awarded on a licence for 15 years for £8,334,000. This is equivalent to £139k per year for 10 MHz of spectrum for the whole of the Great Britain which might amount to £50k per year for the Western Power area if other distribution companies shared the spectrum. This illustrates that small blocks of spectrum which are not harmonised internationally for commodity services can be cost-effective for utility communications.

This situation is reflected in the proposition for harmonised spectrum for 'Utility Operations' proposed by the European Utility Telecommunications Council (EUTC) shown below.

Figure 14: EUTC Spectrum Proposal



EUTC Spectrum Proposal

Within Europe, multiple small allocations within harmonised bands:

- **VHF spectrum (50-200 MHz)** for resilient voice comms & distribution automation for rural and remote areas. [2 x 1 MHz]
- **UHF spectrum (400 MHz band)** for SCADA, automation, smart grids and smart meters. [2 x 3 MHz]
- **Lightly regulated or licence-exempt shared spectrum** for smart meters and mesh networks. (870-876 MHz)
- **L-band region (1500 MHz)** for more data intensive smart grid, security and point-to-multipoint applications. [10 MHz]
- **Public microwave bands (1500 MHz – 58 GHz)** for access to utilities' core fibre networks/strategic resilient back-haul.
- **Public satellite bands** to complement terrestrial services for particular applications.

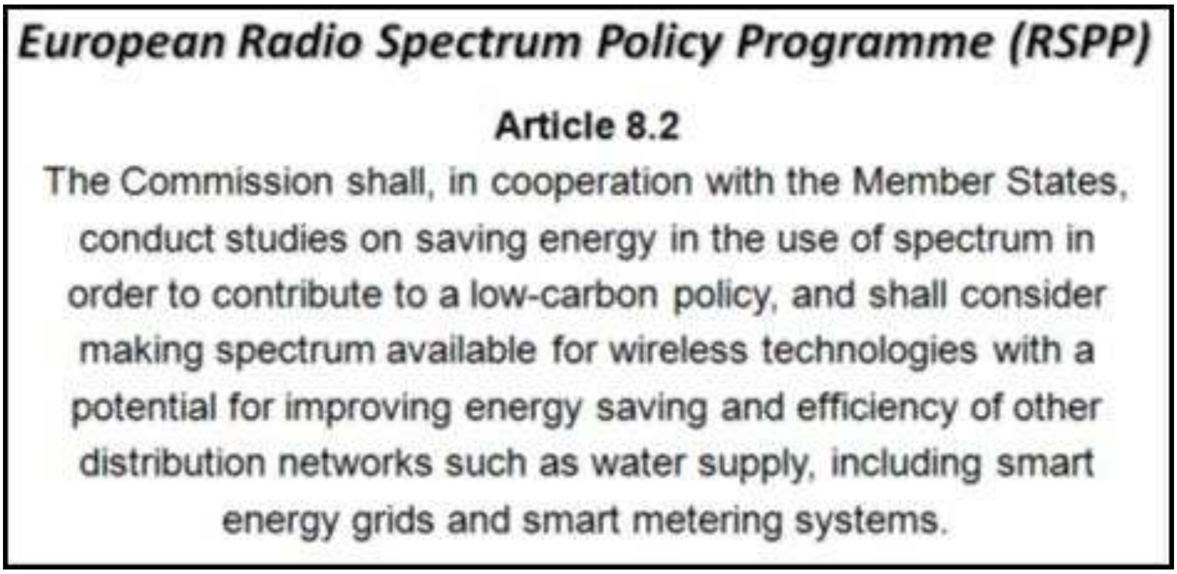
Source: JRC

The radio spectrum around 1400-1500 MHz is ideal for Smart Grid type allocations because of its combination of:

- Range out to about 20km, further in unobstructed paths;
- Medium data capacity up to 2 MBits/s bi-directional;
- Penetration through foliage and to some extent man-made structures; and
- Largely unaffected by atmospheric effects including rain, snow and sleet.

Access to sufficient and suitable radio spectrum is vital to deliver the smart grid benefits to meet energy policy goals. This is recognised in Article 8.2 of the European Radio Spectrum Policy Programme to which the UK subscribes:

Figure 15: European Radio Spectrum Policy Programme



European Radio Spectrum Policy Programme (RSPP)

Article 8.2

The Commission shall, in cooperation with the Member States, conduct studies on saving energy in the use of spectrum in order to contribute to a low-carbon policy, and shall consider making spectrum available for wireless technologies with a potential for improving energy saving and efficiency of other distribution networks such as water supply, including smart energy grids and smart metering systems.

Source: JRC

Although 1400 MHz spectrum has been demonstrated as effective by project FALCON, as illustrated in the EUTC spectrum proposal, spectrum at 400 MHz might be able to deliver equivalent benefits, and it is hoped future Network Innovation Projects might enable the range of frequency bands suitable for smart grids to be clarified.

SECTION 6

Load Estimation

6.1 Executive Summary

FALCON is a research and development project focussing on the 11kV network in and around Milton Keynes. It combined network trials of new smart intervention techniques, such as battery storage and dynamic asset rating, with the creation of a complex network planning tool, the Scenario Investment Model (SIM). This report is a summary of the findings of work in relation to energy modelling which was required to provide load forecasts for use within the SIM.

One of the defining features of Smart Grids is the greater use of information to enable the new technologies and techniques in a more dynamic way. Having a greater understanding of the power flows over the networks will support the optimisation and the operation of networks in real time and also improve the planning of future network investment. This is especially true for network management techniques where timing is important, such as battery charging / discharging cycles, automatic load transfer, dynamic asset rating and demand side management, all of which were trialled under FALCON.

Significant work has been undertaken to better understand what tools and data are available now, what might be available and how to make better use of these. It remains an area of continuing development, but FALCON has provided us with a more informed view of the direction of follow on work..

The objectives within Project FALCON were to:

1. consider the way in which loads at 11kV substations are estimated;
2. determine whether estimation can be an effective substitution for monitoring, and;
3. provide estimates that could be used in the SIM.

The work included creating an initial view of network hotspots where there was the least headroom against voltage or thermal limits. This analysed the network at a greater temporal granularity by modelling over different seasons and days at half hourly intervals. This demonstrated that the network generally had sufficient headroom, but a small number of feeders were approaching their limits and that data quality could greatly impact the assessment of network issues. It also showed that feeders did not all have peak loads at the same time, validating the approach to model at greater temporal granularity.

The mechanism for estimating half hourly load used for settlement was applied to determine the load at distribution substations. Comparisons were drawn to monitored data which showed that substations with more customers were more accurately represented by these estimates. Other features of substations were examined to see how they related to estimate accuracy. Substation load, which often correlates with customer numbers, was also seen to influence estimation accuracy, but other features such as the proportion of load which related to an off-peak tariff, did not.

The substation characteristics of load and customer numbers were used to cluster substations into a small set of types for which average estimate accuracies were calculated. Typical 11kV network feeders were populated with these representative substations to determine the average improvement to accuracy that would result from adding one or more monitoring devices. This found that for underground circuits, monitoring positioned mid-way along the feeder was optimal, but that benefits of additional monitoring devices reduced quickly. Overhead feeders appeared to show a slower decline in added value from additional monitoring such that more than one monitoring device may be more appropriate. Ultimately the value for money calculation would need to quantify the benefits of additional accuracy, which would depend on the purpose of the monitoring.

A significant focus of the load estimation work was to support the development of the FALCON Energy Model by Energy Savings Trust. This was done in partnership with University College London supported with the estimates of load for different demand scenarios.

In order to validate and improve the Energy Model, monitoring equipment was installed in 158 distribution substations throughout the trials area so that estimates could be compared to measured values. The sites were chosen to ensure a range of substation types, sizes and load mixes. A suite of quality metrics was developed to measure how well estimates reflected the actual values.

It was seen that substations with fewer customers were somewhat harder to model accurately and that substations dominated by domestic load were more likely to be modelled well. The quality metrics for estimates produced by the various methods suggest that the Energy Model provides better quality estimates than LV Network Templates or replicating the Elexon process and is considered fit for purpose. This is a positive outcome validating the work undertaken and giving credence to follow on analysis.

A further advantage is that it incorporates meter reading data for half-hourly metered customers. This will become applicable to more customers after April 2016 when the larger non domestic customers (profile classes 5-8) will move to settlement on half hourly metered data.

The analysis highlighted the general need to assess and, if validated, improve the quality of customer data and connectivity data which can be a factor in estimates that are not representative of the real loads. It is suggested that future development of the Energy Model could provide output at a lower level of aggregation to allow for comparison to LV feeder and phase monitoring data, or individual customer data for comparison to smart meter data.
Further work could also usefully include:

- providing estimates on a monthly rather than seasonal basis;

- further work on customer type identification; and
- obtaining as opposed to than assuming opening hours.

6.2 The Need for Better Load Estimation

The 11kV network accounts for a substantial proportion of DNO networks, having feeders with a combined length of cable and overhead lines in the tens of kilometres. Yet HV feeders are likely to include relatively few remotely indicating measuring points, other than in the primary substation or where associated with remote controlled devices. The design standards for 11kV networks should ensure that they operate with some headroom in terms of load capacity so that when networks are unavailable, due to faults or planned outages, the neighbouring networks can carry the additional load. This is typically known as ‘N-1’ when certain assets are unavailable.

The previous approach taken to the network is to ensure that the design is adequate for the most onerous conditions that are expected. Designs have therefore been based on estimates of the maximum load, with assumptions made about the diversity of usage between customers.

The “fit and forget” approach , where there is no continuing feedback from monitoring devices, works well for networks with stable load profiles and low levels of load growth. The proliferation of low carbon technologies however, is likely to impact both the maximum demand and the load profiles for network assets. There is a great deal of uncertainty surrounding low carbon technology in terms of the degree of uptake, the location and the timing. This suggests that analysis should consider more than one scenario to assess the impact of different assumptions on expected outcomes.

Additionally, the new techniques are dynamic, so that in addition to understanding the scale of peak loads there is also a need to know their timing and duration as well as the load profile both before and after the peak. In order to model techniques such as dynamic asset rating, battery storage, automatic load transfer and DSR (Demand Side Response), time series data is required which also needs to reflect the variations between different days in the week or seasons in a year.

For the FALCON Project, it was decided to model load at half-hourly resolution as this fits well with existing industry systems. The five-season model used by Elexon for settlement was adopted with Weekdays, Saturdays and Sundays modelled separately. Three “peak” days were also included to model extreme conditions. Thus, the Load Estimation workstream of FALCON provided load estimates as an input to the modelling within the SIM and provided estimates across:

1. multiple load scenarios due to the level of uncertainty,
2. different seasons and day types to reflect that the most onerous conditions may not always be winter, and
3. at half hourly resolution to support the modelling of time dependent techniques such as dynamic asset rating and DSR.

6.3 Project Objectives

The objectives of the load estimation work within FALCON were as follows:

1. Create a first estimate of half hourly load at distribution substations from available industry data to support the creation of a “rough cut” hot spot map;
2. Compare estimated load values with measured load values to refine the calculation of distribution substation load estimates by feedback methods, then provide a set of improved distribution substation load estimates that can be used to refine the hot spot map;
3. From the comparisons of measured load with the improved load estimates, determine the likely error for derived data for different circumstances (e.g. overhead vs. ground mounted substations, numbers of customers, urban vs. rural). Determine the criticality of such errors in order to determine the optimum balance between derived and measured data required to support the trials in Project FALCON;
4. Create an energy model to generate estimated consumption profiles for customers from configurable models of the drivers of consumption e.g. building efficiency, appliance efficiency, heating technology, electric vehicles and socio-economic factors. This should be applicable to the present day and should facilitate creating demand scenarios that run at least up until 2050 for comparison to other analysis. Improved estimates should be used to further refine the hot spot map and the view of measured vs. derived data as per objectives 2&3 above;
5. Determine new customer profiles that can be used to simplify the process of demand estimation and potentially improve the accuracy of the settlement process; and
6. Define and create a set of load scenarios to be used by the SIM. This should include referencing existing published projects to determine which existing industry load scenarios should be replicated in addition to new scenarios. This will involve the creation of a tool for scenario design and editing, a process which will also investigate the technical details pertaining to such tools and which can continue to be used after FALCON.

6.4 Summary Findings and Suggestions for Follow on Work

During the project it became apparent that the FALCON trials did not require additional estimated data to support the activities such as scheduling of alternative load transfer operations, battery charging or initiating DSR operations as the monitoring that had been installed for these trials provided sufficient information. It also became clear that the Energy Model provided a more complex process than could be represented with a simple set of customer profiles, so those elements of the work were no longer required. This did not affect any of the Successful Delivery Reward Criteria (SDRC) requirements which were all fulfilled and documented in the five reports that were produced during the project.

There are links to these reports in the References & Links section of the Load Estimation report which can be found here: http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-Load-Estimation.aspx.

Rather than repeat the detail of the analysis contained within those reports, this document aims to provide a collective summary of the analysis that was performed and the key learning points. The report will, where appropriate, direct the reader to the appropriate source of detailed information.

The development of the Energy Model was focussed on providing the estimates required for the SIM. While the Energy Model has served its purpose and been proven to work there would be potential enhancements that could be made if this were to be developed into a fully-fledged system. This system would support 11kV planning, preparation of long term plans for price controls, and policy development.

Lower Level of Aggregation
While the Energy Model calculates energy use for each customer the output file provides data for the whole substation. Providing the output for an individual customer or allowing aggregation by LV feeder and phase would allow for use in LV network analysis. This would also assist the process of validation by enabling comparison with feeder and phase level data from the monitoring at Milton Keynes, or smart meter data this may also require improvements in customer-phase data availability).

Customer Type Identification
The matching rates between WPD data for non-domestic customers and the data sources to determine SIC codes, business type, building attributes etc. were generally of low levels. The Half Hourly Metered Customer Archetype Project, funded under IFI, included analysis of half hourly metered customer data to determine whether a set of profiles could be determined to represent a set of customer archetypes. As part of the project matching techniques were developed which have built on and extended the process used in the Energy Model and could be reflected back into the model. Similarly, the archetypal profiles that were developed for different types of organisation could be used as default profiles within the Energy Model where no better profile data is available.

Opening Hours and Occupancy Profiles

Work to improve customer type identification could also obtain better information about operational hours. This would allow for better assumptions for occupancy profiles for non-domestic customers.

Alternatives to Experian Data

The customer level data from Experian which was used to suggest the most likely occupancy pattern and also to drive the clustering factor calculations is costly, to the point of being prohibitive for a more widespread roll-out. Alternative sources of data that could be used as indicators should be considered to reduce overall cost.

Software Implementation

The Energy Model is not a complete system in itself, but requires a significant amount of data preparation. While some of this is included in another executable program there are elements which are calculated manually on spreadsheets with the results then transferred to the relevant tables. A full scale implementation of the Energy Model would need to develop more workable alternatives in keeping with enterprise level software and provide proper system administration tools. Where possible the development should be adapted to support sharing and integration e.g. by handling smart meter data and load estimates in a format consistent with the emerging Common Information Model (IEC standards 61850, 61968, 61970).

Short Term use with Weather Forecasts

The Energy Model uses weather inputs as part of the calculations. For the purposes of generating output for the SIM these were set to seasonal averages. However it would be potentially of great value to see whether the Energy Model could be used with real weather forecast data as an aide to scheduling DSR or similar activities.

Validation Using HV Monitoring

The lack of HV monitoring options has prevented the improvement in accuracy that mid-feeder monitoring could bring to feeder level power flow estimates. This could be incorporated in future projects that already involved extensive monitoring to see the improvement from the application of the calibration calculations.

Alternatives to Elexon Seasons

The length of the Elexon Winter season appears to impact the accuracy of the model. It should be possible to create estimates for each month rather than the Elexon seasons which should reduce some error in the estimates for weather data. This would be especially beneficial for short term forward estimation. While this would generate a larger number of potential day-types these should not all be required for strategic planning.

SECTION 7

Knowledge Capture & Dissemination

7.1 Executive Summary

This document provides a summary of the Knowledge Capture and Dissemination (KCD) workstream and stakeholder engagement processes, integrated across each individual workstream of Project FALCON.

The primary role of the KCD workstream was to ensure each specific workstream in the project was actively collecting, recording and sharing learning where possible. The KCD Lead was also to champion this work and collate relevant material for supporting both internal policy change, integration into Business as Usual (BAU) and targeted dissemination areas.

A further portion of this workstream related to stakeholder engagement, from identification, through management of and active interaction with relevant areas. This piece of work was primarily completed by the KCD partner, The Open University (OU). The section on Stakeholder Analysis contained in sections 4-7 is authored by them with the support from the FALCON team.

From the inception of the project, learning was one of the key elements of Project FALCON and our strategy from the start was to consider three main areas throughout the lifecycle of FALCON:

1. What we wanted to learn from the start;
2. What was learnt along the way; and
3. Dissemination of our learning with relevant audiences.

As part of the Project's contractual obligations, there were a number of Successful Delivery Reward Criteria (SDRC[10]) deliverables as well as ongoing internal milestones.

This document will look at the KCD approach as two separate subsets of work – Knowledge Capture and Dissemination, and Stakeholder Analysis and Engagement. It will also look at what has worked well and what could be improved for future projects, both for BAU and further innovation initiatives.

In summary our conclusions are that despite some challenges throughout the lifecycle of the project, there has been valuable learning from it and in particular in the following examples:

4. Telecoms: WiMAX is currently perceived to be too high cost when compared against other technologies, however this hypothesis will be tested further as part of the proposed Telecoms Templates Network Innovation Competition (NIC) project;
5. Engineering: The energy storage trials delivered strong results, despite still being a high cost to deploy; meshed networks delivered load changes but not on the heavily loaded source breaker during peak; the Automated Load Transfer (ALT) algorithms did

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[10] These are shown in Appendix B of the KCD Final Report.

have a beneficial impact on losses and overhead minimum voltages whilst Dynamic Asset Rating (DAR) showed that use of real time dynamic ratings is hugely variable despite the modelling;

6. Commercial Trials: deemed widely successful; generating significant learning about how Demand Side Response (DSR) could be utilised by a DNO. It was discovered that whilst the capacity used on the 11kV trial network was indeed useful, there were more significant benefits to be explored on higher voltage networks; and
7. SIM: A complex 11kV network simulation system was developed and used to model the network evolution for the trials area forward from 2015, out to as far as 2050 under a range of scenarios. This tool used a detailed nodal model of the network (the subject of the Authorised Network Model workstream). Load models obtained from the FALCON Energy model, a cost model and a large software system centred on a kernel element based on the IPSA power analysis tool. This tool worked but was complex to implement and is being further developed and refined to yield more results in the coming months.

7.2 Approach to Knowledge Management

During the bid and design phases, the UoB were the appointed project partner to capture knowledge and support dissemination accordingly.

Following a period of review and discussion after the start of the build phase it was decided that KCD should be brought in house within the project team and the existing partner contract was ended. It was felt that by having such a key part of the project both on site and led by a team member with a DNO background, it would be more productive and deliver the quality expected by a project such as FALCON.

The existing approach was re-assessed and an adapted KCD strategy agreed with Ofgem as part of a formal change to the project.

Each Workstream Lead was expected to retain an ongoing learning document, with this working best in the Telecoms workstream, with a diarised storybook being retained by the Lead. Whilst this enabled the ongoing capture of learning, it also provides a historic detailed record of the both the benefits and challenges of some of the process. This approach is being considered as the most successful, cost effective way of individual leads maintaining a personal record.

Below, we go on to describe the “revised” KCD approach and how KCD was managed within the confines of the project.

A number of formats and regular review points were agreed with each team member at the outset – this ranged from group workshops and team meetings, through to individual interviews and site surveys or accompanied visits, with each approach tailored to the relevant personnel to limit intrusion, but maximise effectiveness.

During the bid and design phase, a number of questions were posed that were expected to be relevant to each workstream and these were retained as the early learning outcomes. If they began to fall out of scope, or became less relevant as the project moved along, this would be captured in the progress reports. An example of these, published in our original Project Initiation Document (PID) is shown in Appendix A of the KCD Final Report.

This began to grow a suite of early learning outcomes and led on to form wider high level topic areas, expected to be key to discovering how each of the techniques could be relevant to the industry, to each other and to inform next steps. Figure 1 below, provides an indication of how it was expected these outcomes would be addressed. I.e. by moving them from concept, into WPD Policy and/or disseminating them into the relevant stakeholder section.

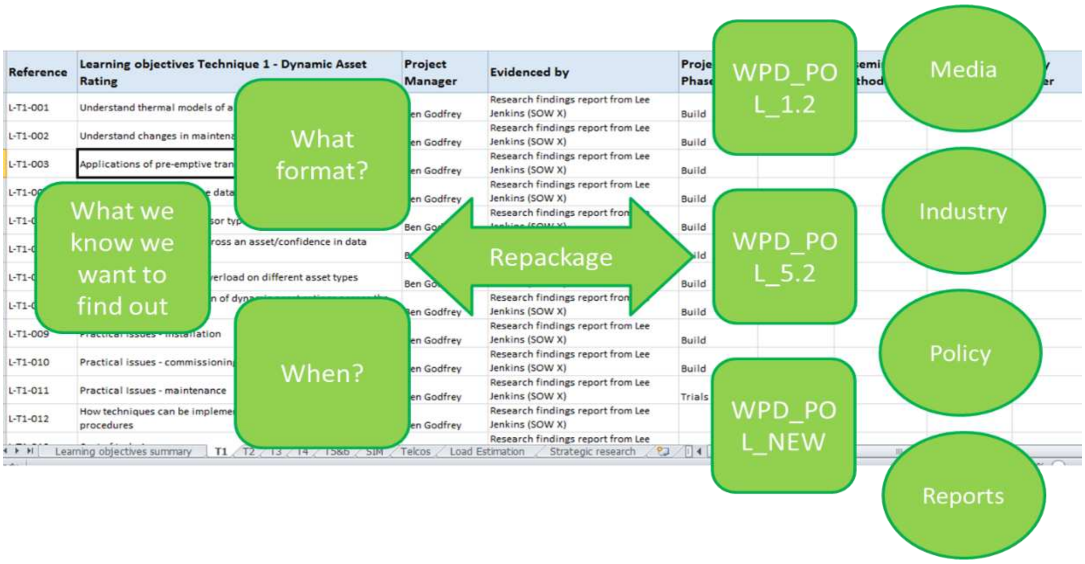

Figure 16 – Learning Outcomes

Whilst these early outcomes provided somewhere to work from, there was as much desire to discover and capture the learning that was not predicted or foreseen.

The very nature of an R&D project did mean there was likely to be ‘negative’ learning, so every effort was made to continue to communicate this across the team on a regular basis. Where something may have been a challenge for FALCON, it remained vital that this was communicated to our colleagues elsewhere to ensure the same path was not followed, or to simply allow the industry to benefit from FALCON’s new learning. When a process didn’t go according to plan or deliver the anticipated results, it was important to reinforce this fact to maintain the KCD strategy.

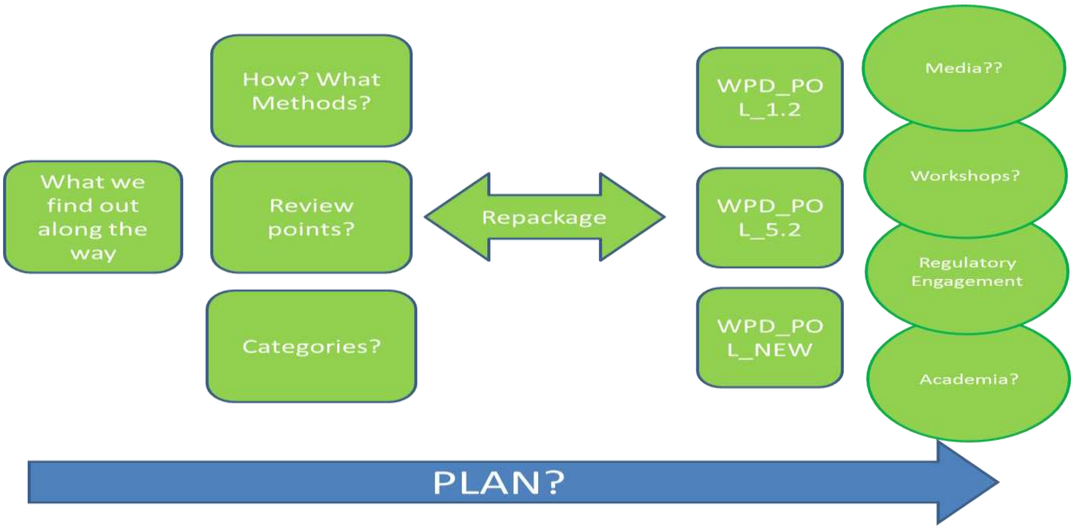

Figure 17 New Learning

A purpose made spreadsheet was developed, to allow smaller pieces of learning to be captured on a regular basis across each workstream area. The intention being that both throughout the Project and towards the end, each area of learning could be shared on a targeted basis, as opposed to a blanket approach, which given our experience to date on similar projects across the industry, had led to broader dissemination schemes. We felt that by maintaining tighter grouped areas of knowledge, we could offer more to our stakeholders in a targeted approach.

The spreadsheet was built to encompass the 'what do we want to learn outcome' and integrate the key 'what did we pick up along the way' outcomes. Each line item would be assigned an owner, a timestamp, how/if it was integrated into BAU and where it would be disseminated, where relevant.

As the Project progressed, it was agreed to cluster these learning outcomes into a hierarchal format to make it easier for both reporting and recording in the future and to balance the volume of smaller learning areas that was being collected.

The simple learning hierarchy is described in the picture in Figure 3 below, with learning outcomes being grouped into a learning topic.

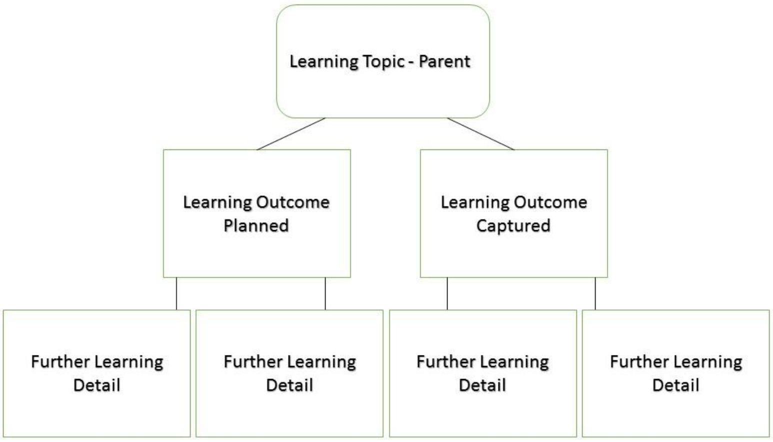

Figure 18 – Learning Hierarchy

This approach allowed any detail to be collated at any level before being added to the database of learning for the Project. Furthermore, by developing broader learning topics for each workstream, the reporting process was supported with a structure as the Project drew to a close. Again, this also went on to inform our dissemination strategy and areas of relevance pertinent to each stakeholder grouping.

As the Project closed out, the data could also be retained by WPD for research in the future or to reflect on what worked when re-developing processes and technology.

At the outset of the Project, each learning outcome, topic area or item of knowledge capture was to fall into one of the eight categories covering WPD's low carbon learning:

- Customer Engagement;

- Project Management;
- Construction Process;
- Technology & Equipment;
- IT & Telecommunications;
- People and Culture;
- Industry Processes & Regulation; and
- Stakeholder Analysis.

Each area of learning is linked to the relevant category allowing WPD to take a view at a high level, how each of their innovative projects informs the industry, or the business and more importantly in what area.

From the outset, it was understood that FALCON would deliver heavily in learning around Technology & Equipment and IT & Telecommunications, as opposed to Customer Engagement, for example. Whilst FALCON was designed to support the customer, much of the work related to ‘behind the scenes’ developments as opposed to customer change or interaction, with the exception of the DSR trials. This resulted in wider interest from technology providers, other industry members and engineering stakeholders.

7.3 Approach to Dissemination

A balance between those things that would be done in BAU, such as wider industry event appearances, through to arranging specific FALCON engagement events was needed throughout. Whilst the desire to benefit from the multitude of conferences in the UK was there, it was also apparent that these had to be selected carefully, as both preparation time and indeed the event itself invariably required a large amount of resource.

The mobilisation through to mid-build phase was managed by the University of Bath appointed at the outset. The initial plan was to disseminate learnings using a number of communication vehicles. These included a bespoke Low Carbon UK website managed by University of Bath, as well as a number of podcasts designed by University of Bath and The OU along with a regular newsletter.

During the Build phase, University of Bath were replaced and an in house appointment was made, as explained in the previous section.

As such, the approach was updated to take a more targeted stakeholder engagement view and utilise as many cost effective measures as possible. A workshop led by the FALCON KCD Lead including Corporate Communications, the FALCON Project Manager and the outsourced PR unit was held, to identify and agree an updated strategy for dissemination. Whilst digital media, such as podcasts, remains popular and effective, it became time consuming and it was felt as much could be made through exploiting as many other channels as possible, except without the added costs of digitisation.

The Communications Plan was updated accordingly and the role was split into two key areas – internal direct dissemination and external dissemination. The plan was adopted to integrate both the measureable dissemination pieces, such as the SDRC requirements, as well as those focussed on other key areas of the industry.

The internal piece of work was aimed to both increase awareness inside WPD, and begin any transfer into BAU of technology, via normal policy channels, as well as raise the project profile with a series of articles in the internal company magazine, Powerlines, distributed to 30,000 employees past and present. An internal bulletin board on the Corporate Intranet to support informing the business was also created.

The SIM workstream also engaged with a user group containing both strategic planner users and 11kV planners. A regular newsletter for this user group was also issued.

External dissemination was made up of a number of different channels including:

- The completion of the existing podcasts from University of Bath;
- A FALCON Newsletter – explaining and sharing direct data from each of the FALCON Workstream areas;
- WPD Innovation Online – a refreshed FALCON website to include all documentation published to date and media links;
- Social Media – a new social media channel was created to embed the technique videos, podcasts and dissemination events. A LinkedIn profile was also created to share event details;
- Dissemination Academic/Industrial Conferences – WPD led conferences were planned to share major milestones and achievements;
- Speaking Roles – a number of wider industry events were targeted for specific engagement purposes and to consult with stakeholders on results and findings; and
- Model Presentations – the FALCON team presented at larger events as well as smaller more niche areas, utilising the innovative technique display models that were designed and built.

Table 2: Dissemination Soundbite

Sean Rendall
‘Thameswey recognised FALCON as an opportunity to add value to our distribution networks by enabling further participation in Demand Response schemes. The presentation to our board was useful to gain support for this drive into innovative schemes'.

Source: Sean Rendall, Operations Manager, Thameswey Group (FALCON Commercial Trials Participant).

Being conscious of the levels of dissemination, one of the aims was to consider how many dissemination channels there were, the cost and associated carbon footprint with each of them and any quantifiable measures available, such as footfall, questions or direct feedback. Whilst some of the events are widely attended, it was most relevant to the team, that the attendance be relevant to the project and not become a wider DNO stakeholder session, for which other major events were held.

The external dissemination also encompassed more formal contact with our colleagues in the industry and those involved in policy. A number of SDRC targets were agreed and amongst these, a number of different consultations were both necessary and useful to achieve them. Whilst this meant feedback was an important next step, it also provided the industry an opportunity to consult on our proposal and benefit from any learning available at that time.

A year planner was designed, with resource borne in mind, to ensure that the KCD Lead, Project Manager, Programme Manager and Project Sponsor had clear dedicated timeslots to engage with internal and external stakeholders.

Table 3: Presentation Soundbite

Robert McNamara
'Our joint dissemination event with the WPD FALCON team was a real chance for our stakeholders to learn more about the Project and really engage the key players in feedback'.

Source: Rob McNamara, Executive Director, SmartGridGB/TechUK.

The FALCON speaking and stakeholder facing engagements varied from formal presentation events, such as that at MK Dons, to local informal briefing sessions with technology providers, partners and industry stakeholders.

It was at this early stage, on reflection, that one of the best dissemination pieces was created in the form of five interactive models demonstrating the four engineering techniques and DSR. Whilst the models were effective in communicating stand alone, they were convenient enough to be able to present to any audience, from children, to Senior Engineers simply by altering the explanation to the suit the person/s listening. Figure 4 shows one of the many events the models were displayed and demonstrated at.

Further detail on our dissemination activity is included in Appendix C of the KCD final report.

Figure 19: Varied FALCON Speaking Engagements

Source: FALCON Team

7.4 Stakeholder Engagement

The OU were retained after the University of Bath contract ended, to continue in their support capacity. As a local stakeholder they were engaged to support the KCD workstream through stakeholder analysis, qualitative analysis and assist with the dissemination activities in general.

The purpose of stakeholder analysis was to identify priority stakeholders and modes to manage relationships with them. The approach to stakeholder analysis in this project defines a stakeholder as:

'Any group or individual who can affect or is affected by the achievement of the organisation's objectives' (Freeman 2010:46)[11].

Prioritising stakeholders was an ongoing process undertaken by members of the FALCON team. Specialist inputs in stakeholder engagement were supplied by the OU team to support this ongoing process.

The early approach was to identify those associated with FALCON and identify categories for each grouping. This was to follow a project-centric logic with priority stakeholders identified in light of the project objectives.

Engagement was undertaken iteratively, consequently stakeholder engagement was modified as the Project progressed and new stakeholders joined or emerged. Priority stakeholders were identified during the mobilisation, design and build phases and modes of engaging them were identified. As the build phase moved into the trials phase these were further developed to allow appropriate dissemination and engagement during the conclusion(s) and sharing phases.

The broader approach to stakeholder engagement was to stimulate a two-way dialogue with stakeholders involved in FALCON providing and gaining meaningful feedback. This was done by using three wider modes of engagement:

1. **PASSIVE:** Informing/explaining – the release of information to stakeholders as a means to be open and transparent about the objectives. Information includes decisions taken by the Project that may affect or be of interest;
2. **INVOLVED:** Consultation – engaging stakeholders to provide advice on the Project's decisions and/or objectives;
3. **ACTIVE:** Collaboration/partnership – looking to achieve objectives that are mutually beneficial to both the Project and the stakeholders involved.

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[11] Freeman, R, E., 2010. Strategic Management: A Stakeholder Approach (digitally printed version). Cambridge University Press, UK.

As the Project progressed into the trials phase, it was expected that from a number of events, semi-structured interviews and discussions, both internally and externally, a solid level of understanding could be achieved.

This stakeholder engagement piece was also designed to continue throughout the Project internally, to look at both cultural change, awareness and impacts the Project had across the key internal stakeholders. A series of interviews, meetings and workshops were conducted internally throughout the FALCON lifecycle, by the KCD Lead supported by The OU. These were with relevant members of the Business and the Project, with a focus on, but not limited to:

- The Future Networks Manager – responsible for all innovation activity across WPD and Programme Manager for both FALCON and other similar schemes;
- The Distribution Manager – responsible for the entire geographical area where the FALCON trials operated;
- The FALCON Project Manager – responsible for the day to day operation of FALCON and any additional liaison between the Business and the Project team;
- The FALCON Workstream Leads – both contracted specialists and internal Future Networks team members;
- FALCON Engineering – both BAU team members and FALCON specialist staff involved in the installation and operation of FALCON systems; and
- Project Partners – those providing specialist support roles such as CGI.

There were also a number of more informal sessions with installation teams and fitters who were involved in the actual installation and/or operation of some of the engineering and communications equipment. Much of this was completed on site to capture changes, improvements or to support the writing of reports, dissemination pieces or internal policy submissions.

Table 4: Consultation Soundbite

Ian Cooper
‘We (UK Power Networks) really appreciated our knowledge sharing visit to FALCON’s energy storage project and found it useful to attend. Seeing first-hand the equipment installed and being able to discuss insights from the FALCON team was helpful in preparing for the operational phase of the Smarter Network Storage project.’

Source: Ian Cooper, Smarter Network Storage, Future Networks, UK Power Networks.

7.5 Knowledge Management

A number of areas of knowledge management grew during this Project and the approach has both informed and supported other similar projects in house.

Historically BAU projects have been solely engineering led, with fewer research and development projects taking place in the areas across low carbon development. Whilst the Project was keen to learn in the defined scope of itself, it was also expecting to support best practice in knowledge capture and dissemination as a whole.

Overall, the Project can be deemed successful in terms of knowledge gained in new areas. Whilst the team remained keen to alleviate every small challenge where possible, the very nature of an R&D project is to identify where these types of challenge actually exist.

The Project produced vast areas of learning for both WPD and the industry. There are some key points coming from the process, including:

7.5.1 Key Learning

- Due to the nature of the business operations, with maximum cyber security and thus limited external connectivity, much of the KCD process operated independently of the main business unit;
- The geographic spread of the main business unit, the Project partners and the specialist support staff meant that regular team days were crucial in the early parts of the Project;
- The original KCD Lead was a remote academic partner. Whilst their approach differed from the in house lead, it became apparent that having this role at the heart of the Project on a daily basis, not only allowed the ongoing championing of the role, but also the effective support of it;
- Conflicting workloads for required staff need to be prioritised in advance in accordance with the Project plan;
- Contract and partner management requires a thorough approach and regular agreed review dates to ensure the scope remains fit and the deliverables on target; and
- A pre-planned programme of events and review points with relevant parts of the business to be agreed at the outset, with defined dates clearly identified and made known.

7.5.2 Recommendations

- The early development of an online repository and/or library for the both the internal capture of knowledge and a separate managed output direct to the internet for external knowledge sharing; and
- The build of a suitable database to replace the spreadsheet formats to aid in knowledge capture.

7.6 Dissemination

It was identified early on that dissemination is a large area and certain parts of the Project would naturally attract more attention than others. For example, as energy storage became a more exciting global topic as FALCON progressed, more interest was received in this area of the Project. The real benefit of this type of increase to Technology Readiness (Levels) being that organic dissemination was produced i.e. specific information requested from FALCON without a substantive need to carry out stakeholder analysis (or the identification of stakeholder groupings).

There is a large industry in media and dissemination itself and along with this comes fairly regular requests for speaking appearances or content provision for many of the utility, smart grid or innovation conferences.

The Project was very keen to maintain the best use of resource and time, bearing in mind the carbon footprint of travelling great distances for short periods of time.

Some areas of dissemination were far more successful than others and some much more cost effective than others.

7.6.1 Key Learning

- The dissemination plan worked well. With a plan to complement the stakeholder engagement strategy, planning the year ahead to meet targets and deliverables (such as SDRCs) was generally successful. Such plans need to be reviewed every month to ensure maximum resource efficiency when taking into account team members geographic spread;
- After the appointment of an in house lead, the volume of digital output that was in the original plan was reduced. Podcasts and digital media are effective tools for communication, however, there were more cost effective communication methods available, such as a regular industry newsletter and the utilisation of existing social media channels (the WPD YouTube channel, Twitter and LinkedIn profiles were all created during FALCON);
- By far one of the most successful pieces of commissioned work, was the design and build of a suite of interactives models that demonstrated each intervention technique. The models were designed so the presenting part could effectively target them at any audience whatsoever. They are shown here;
- Some Project areas naturally attracted significant interest over others. For example the development of electrical energy storage during the Project allowed for organic dissemination as the findings became more apparent;
- It became clear that certain areas were more suitable to certain audiences rather than the previous, one size fits all methodology. With such a wide ranging Project scope and moreover, set of findings, we have found the stakeholder groupings much more relevant to disseminating more detailed findings;
- The webinars conducted in the later stages were very successful indeed. With zero travel necessary, it was estimated that for an audience of 50, at an average journey time of two hours return, a broad economical saving was made of ~100 people hours. On top of this, the carbon footprint was negated completely; and
- By directly engaging editorial staff, we ran a number of in print and online feature articles in many of the mainstream industry publications, including E&T (The IET's magazine), Utility Week and tdworld.com.

7.6.2 Recommendations

- Customer engagement for this Project was lower than other similar projects across the business. This was due to the engineering and 'behind the scenes' software driven targets, however, we believe a demonstration day, or event, could have been held for local residents both at the depot and at a key town centre location to show how DNOs are working towards the future together;

- Schools engagement requires a significant amount of planning when compared to normal dissemination channels. Whilst FALCON was successful in presenting to local schools, it became more apparent that dovetailing into both academic years, appropriate school children and planning outings was very hard. The process for example, to invite a group of science and engineering students, to the Project depot in Milton Keynes, was arduous as both a number of pre site checks, permits and written permissions were required well in advance, making it too late for this Project to continue with a visit;
- WPD worked with a local energy charity with existing relationships, to expedite engagement with Industrial and Commercial organisations within the trial area, for the purposes of identifying potential participants for the commercial trials. It was apparent after a very short period of their attempted engagement that they would either require significantly more training or strict limits on the extent of the discussions into which they could participate alone. In order to manage the accuracy of any public message, WPD needs to maintain ownership of the process and ensure that the process is strictly monitored; and
- When engaging potential participants for DSR, many of the industrial and commercial facilities within the trial area are owned by National or International organisations. This typically resulted in any decision makers and key stakeholders who required to be consulted, being located outside the trials area of the potentially the entire DNO license area. This will need to be addressed as this work moves towards BAU.

Table 5: Dissemination Soundbite

Mei Lin Lim
Malaysian utility, Tenaga Nasional Berhad's (TNB) visit to Western Power Distribution was very informative. The openness in knowledge sharing on FALCON engineering trials, Cisco technology on the communications as well as areas of other consideration, has given useful insight which has helped TNB's Smart Grids plan in moving forward.

Source: Mei Lin Lim, Cisco APAC, Singapore Division.

A number of areas of knowledge management grew during this Project and the approach has both informed and supported other similar projects in house.

Historically BAU projects have been solely engineering led, with less research and development projects taking place in the areas across low carbon development. Whilst the Project was keen to learn in the defined scope of itself, it was also expecting to support best practice in knowledge capture and dissemination as a whole.

On the whole, the Project can be deemed successful in terms of knowledge gained in new areas. Whilst the team remained keen to alleviate every small challenge where possible, the very nature of an R&D project is to identify where these types of challenge actually exist.

The Project produced vast areas of learning for both WPD and the industry. There are area some key points coming from the process, including:

7.6.3 Key Learning

- Due to the nature of the business operations, with maximum cyber security and thus limited external connectivity, much of the KCD process operated independently of the main business unit;
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7.7 Dissemination

It was identified early on that dissemination is a large area and certain parts of the Project would naturally attract more attention than others. For example, as energy storage became a more exciting global topic as FALCON progressed, more interest was received in this area of the Project and consequently we received a substantial amount of focus on storage. The real benefit of this type of increase to Technology Readiness (Levels) being that organic dissemination was produced i.e. specific information requested from FALCON without a substantive need to carry out stakeholder analysis (or the identification of stakeholder groupings).

There is a large industry in media and dissemination itself and along with this comes fairly regular requests for speaking appearances or content provision for many of the utility, smart grid or innovation conferences.

The Project was very keen to maintain the best of resource and time, bearing in mind the carbon footprint of travelling great distances for short periods of time.

Some areas of dissemination were far more successful than others and some much more cost effective than others.

7.7.1 Key Learning

- The dissemination plan worked well. With a plan to complement the stakeholder engagement strategy, planning the year ahead to meet targets and deliverables (such as SDRCs) was generally successful. This plan needs to be reviewed every month to ensure maximum resource efficiency when considering team members geographic spread;
- After the appointment of an in house lead, the volume of digital output that was in the original plan was reduced. Podcasts and digital media are effective tools for communication, however, there were more cost effective communication methods available, such as a regular industry newsletter and the utilisation of existing social media channels (the corporate YouTube channel, Twitter and LinkedIn profiles were all created during FALCON);
- By far one of the most successful pieces of commissioned work, was the design and build of a suite of interactives models that demonstrated each technique. The models were designed so the presenting part could effectively target them at any audience whatsoever. They are shown here;
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- It became clear that certain areas were more suitable to certain audiences rather than the previous, one size fits all methodology. With such a wide ranging Project scope and moreover, set of findings, we have found the stakeholder groupings much more relevant to disseminating more detailed findings;
- The webinars conducted in the later stages were very successful indeed. With zero travel necessary, it was estimated that for an audience of 50, at an average journey time of two hours return, a broad economical saving was made of ~100 people hours. On top of this, the carbon footprint was negated completely; and
- By directly engaging editorial staff, we ran a number of in print and online feature articles in many of the mainstream industry publications, including E&T (The IET’s magazine), Utility Week and tdworld.com.

7.7.2 Recommendations

- Customer engagement for this Project was lower than other similar projects across the business. This was due to the engineering and ‘behind the scenes’ software driven targets, however, we believe for the better of the industry, a demonstration day, or event, could have been held for local residents both at the depot and at a key town centre location to show how DNOs are working towards the future together;

Schools engagement requires a significant amount of planning when compared to normal dissemination channels. Whilst FALCON was successful in presenting to local schools, it became more apparent that dovetailing into both academic years, appropriate school children and planning outings was very hard. The process for example, to invite a group of science and engineering students, to the Project depot in Milton Keynes, was arduous as both a number of pre site checks, permits and written permissions were required well in advance, making it too late for this Project to continue with a visit.

SECTION 8

Qualification of benefits

8.1 Executive Summary

This section provides a brief summary of the approach to benefits taken on Project FALCON and provides an update on what the overall benefits could be of adopting the techniques trialled within the project. There are of course a number of assumptions that the team has made throughout the document and these are detailed throughout the report.

The approach from the outset was to focus on longer term validation of the potential benefits rather than those within the project lifecycle. This was because as the network trials area in Milton Keynes was not constrained in any way, no benefits could actually be attributed within the project lifecycle. In order therefore to validate the benefits there had to be a methodology of evaluating the potential cost benefits of each of the engineering and commercial trials.

This was intended to be done by creating a couple of models that would measure financial and carbon benefits for each of the techniques- however this proved cumbersome given the complexity of costs and the potential for cross subsidy(it was not possible to evaluate each cost element of each technique in isolation). Therefore the validation method chosen was to run the SIM for a chosen area with and without the techniques implemented. This would therefore tell us the overall cost differential between traditional reinforcement and a solution with all the techniques utilised.

The Scenario Investment Model (SIM) was used to carry out long term investment studies on five primaries within the Milton Keynes area. Comparing results of studies that included smart techniques with those that only applied conventional reinforcement techniques suggested significant savings in Totex could be achieved as the result of deploying dynamic asset rating and meshed networks with some niche application of other smart techniques. To ensure the widest range of opportunity for applying dynamic asset rating threshold levels for thermal overload were set low, with thermal issues being raised when assets are more than 1% of their normal rating. This will tend to overestimate the benefits of smart techniques as reinforcement would not be planned on the basis of such a low level of overload therefore the Totex reduction is expected to be in the region of 20% subject to confirmation via sensitivity analysis. Additionally a wide variation was seen between the results for individual primaries suggesting that rather than applying an average value it would be useful to extend the analysis and determine whether primaries can be categorised to better estimate their potential benefits. General trends were more consistent, with smart techniques reducing Capex while increasing Opex, and the creation of meshed networks resulting in reduced CMLs and CIs. Further details are given in the SIM report which can be found here : http://www.westernpowerinnovation.co.uk/Document-library/2015/Project-FALCON-SIM.aspx.

8.2 Background - Project

FALCON was a research and development project focussing on the 11kV network in and around Milton Keynes. It combined network trials of smart techniques, such as battery storage and dynamic asset rating, as well as commercial tools, with the creation of a complex network planning tool, the Scenario Investment Model (SIM). It also included a new telecommunications network.

As part of the project and its submission for funding there were a number of potential benefits considered and as in all research projects part of the analysis and trialling was the measurement and realisation of those benefits.

This document discusses the approach taken and provides a series of conclusions.

8.3 Background- Benefits

Within the original bid document there were a few indicators given around the expected benefits of FALCON. Those benefits fell in the usual categories of Financial (direct and indirect) and carbon emissions (reductions and/or savings).

It was initially expected that any benefits would either occur within the lifecycle of the project or alternatively beyond the lifecycle of the project. However, as the bid developed it became apparent that benefits within the lifecycle of the project would be hard to quantify due to the area used in the trials and therefore it was stated that no benefits would occur within the lifecycle of the project.

As part of the benefits management work stream it was deemed appropriate to ensure that, at least in the early stages of the project as the scope and detail of the project became clearer, that more data would be available in order to give an early indicator of likely benefits. Therefore a piece of work was undertaken to provide measurement tools for the team to ensure that benefits if found, could be measured.

8.4 Description of Approach

Our approach at the outset was to determine the appropriate network to be used for the trials and ultimately the modelling within the SIM. Whilst it was always a desire to use a piece of constrained network, this was not possible within the geographic location of Milton Keynes. This meant that the potential for benefits within the lifecycle of the project diminished, but as we had stated that no benefits were likely to be determined within the period of the project this was not deemed to be an overly pressing issue. Milton Keynes is an area with strong low carbon ambitions and it is likely that the area will eventually benefit from the equipment installed as part of the trials, such as the communications network. Therefore during the duration of the project we have reported no tangible financial or environmental benefits.

At the start of the project we set about trying to determine for each of the techniques where benefits would occur and how they could be measured. This required extensive analysis to determine the variety of factors that would need to be measured.

A relatively simple “input” tool was developed from this work to measure the potential benefits. However as the trials developed it was found that maintaining this tool was going to be considerable effort and also that separating out the various costs for the trials from on-costs was extremely complex. The project team therefore set about trying to determine a much simpler way of determining and measuring associated and potential benefits. This led the team to concluding that the easiest and most effective way of measuring benefit would be to measure the cost differential between conventional reinforcement within the FALCON area and compare this with the costs associated with the various techniques within the SIM.

8.5 Initial Benefits Analysis

There were two potential benefits for FALCON as follows and this thinking formed part of the original bid submission.

8.5.1 Within project lifecycle

As previously stated we determined quite early on that there would be no significant direct benefits (either carbon or financial) during the course of the project trials, as there is no change to the then existing DR5 plan.

8.5.2 Outside project lifecycle

At the start of the project the stated expected opportunities for benefits were as follows:

1) Net investment financial benefits of £1.2m after the trial period from delayed or invested reinforcement to the network.

- These savings were based on estimates derived from an Imperial College & ENA paper (Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks, Summary Report V2.0[12]) on national network investment needed in the 2020-2030 period in order to cope with increased demand from and load input to the HV network.
- Net financial savings were calculated as the difference in investment between "business as usual" investment (BaU) and smart grid investment to cope with this modelled growth in demand. This was the calculation of choice for the techniques and trials in this project.
- The paper derived models of electricity demand growth and profile changes on the UK HV and LV networks. Primarily responsible for these changes are the increase in electric vehicle and heat pump use, as well as underlying assumptions about increases in energy efficiency for buildings.
- Our estimates for £1.2m saving on infrastructure were based on using a BAU investment in HV grids (£3.7bn taken from the Table 6.1 of the paper) less the 13 calculated investment needed using these smart grid technologies nationally during the same period (including modelling their roll out, effectiveness, penetration and actual savings). This is then normalised to the size of the trial area by the number of customers in the area as a percentage of national number of customers.

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[12] http://www.energynetworks.org/modx/assets/files/electricity/futures/smart_meters/Smart_Metering_Benerfits_Summary_ENASEDGImperial_100409.pdf

13 http://www.energynetworks.org/modx/assets/files/electricity/futures/smart_meters/Smart_Metering_Benerfits_Summary_ENASEDGImperial_100409.pdf

- Various technology penetrations were modelled between 2020-2030, assuming a starting point of 5% by 2020. We selected their mid-range 50% penetration level of electric vehicles (EVs) and electric heat pumps (HPs) by 2030.
- To derive projected figures for the project using these national figures, we have estimated the percentage of the UK covered by the project area (55,000 customers as opposed to 28.7m across UK) to be 0.19%.
- To refine this figure further, we have estimated the % projected uptake of the techniques we are investigating across the country, their effectiveness and their cost saving to an overall figure of ~36%. This, along with an estimated 50% roll out across reinforcement projects, is then applied to give national costs of infrastructure investment under smart grid trials
- 35.625% * 50% * £3700m = £ 659m
- Hence total costs of HV reinforcement in the trial area from 2020 - 2030 are following smart grid trials:
  - (BAU – smart) * (% trial size vs national) = (3700 – 659) * 0.19% = £5.8m
- This compares with HV reinforcement estimates of under BAU scenario for the trial area of:
  - BAU investment * (% trial size vs national) = 3700 * 0.19% - £7m
- Total savings in the area are then projected to be :
  - £7m - £5.8m = £1.2m (2020-2030)

2) Other financial

Provide faster and cheaper 11kV connections and reduced DUoS charge increases for all customers

3) Carbon benefits

• national rollout of FALCON estimated to realise a £660m financial benefit over 20 years and save over 680 k tonnes of CO2 by 2050 (accounting for an additional £36m of benefits)

• enable the uptake of low carbon technologies

4) Intangible

• Learnings about the effectiveness of alternative techniques to traditional reinforcement both in terms of operational processes and customer behaviour

• Ability to scenario plan various investment decisions for network reinforcement (in the SIM model). This will allow planners (both in WPD and in the wider community) to estimate from field trials both financial and carbon impacts of various investment scenarios to shape the most appropriate investment decisions.

• generate learning applicable to all DNOs

We have found with the LV Network Templates project that the data collected from substation monitoring has been used by several third parties for additional analysis and we expect the same to be true for the Milton Keynes data

These measures validate the statements within the original bid document, and whilst there were no direct benefits we have attempted to validate the future benefits by undertaking some analysis within the SIM.

8.6 Results and Findings

We have run the DECC 1-4 Scenarios within the SIM and then run the SIM again for DECC 4 but with the techniques removed, therefore only utilising conventional reinforcement. This produces a result that we have then compared back to DECC4 to measure the potential benefits for the techniques used. This is an efficient way of getting a view of where there may well be cost savings.

As mentioned previously the results were determined over 5 primaries within the Milton Keynes area and there were indeed some savings where utilising the smart techniques, and in particular though not unexpectedly, with DAR. These savings were in the order of 30% in Totex. However, given the wide variation between individual primaries, and that we believe that this may overstate the benefits associated with DAR, we believe that a value of 20% is more representative (and is the mid range of the savings shown in the table below). Further sensitivity analysis is planned to help refine this figure.

Totex All values in £k (2015)	**Bletchley**	**Childs Way**	**Fox Milne**	**Marlborough Street**	**Secklow Gate**	**Total**
DECC4 traditional only costs	2,809	1,254	274	3,824	7	8,168
Decc 4 all techniques cost	2,064	1,222	173	2,267	6	5,732
saving	745	32	102	1,557	1	2,436
Percentage saving	27%	3%	37%	41%	11%	30%

The following additional thoughts and caveats come with this number:

1. The trends from the metrics indicate reductions in CML’s
2. But consequently we see losses increasing because the impact of the increase in load under all scenarios outweighs the benefits from meshed networks.
3. Given the size of the snapshot we do think that a mid range 20% saving is a positive outcome, but of course it would need additional validation In order to determine a

valid likely cost saving the analysis would have to be extensively modelled across the WPD regions.

4. We do believe that there is some potential analysis that could be done to further validate our numbers. This is something that we are currently exploring.

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