WPD INNOVATION

Transforming the electricity network

Electricity Flexibility and Forecasting System Project

Close Down Report

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Western Power Distribution 2021

Contents

1. Project Title and Background

Electricity Flexibility and Forecasting System (EFFS)

The electricity network is changing, with higher levels of embedded generation, the emergence of storage and the uptake of low carbon technologies such as electric vehicles and heat pumps. These changes pose challenges for networks that were not designed to include them and Distribution Network Operators (DNOs) have been investigating a range of innovations to enable smarter networks, enabling low carbon generation without the cost and delays associated with traditional reinforcement.

Recently, it has been acknowledged that managing the challenges of future networks will require DNOs to adopt the new role of Distribution System Operator (DSO), which, alongside greater co-ordination with the Transmission System Operator (TSO), will involve making greater use of flexibility services to operate a far more dynamic network.

The Government's recent report "Updating our Energy System: Smart Systems and Flexibility Plan" includes specific actions for DNOs to help create markets which work for flexibility, requiring DNOs to "develop timely and appropriate reforms to the way they plan, operate and engage with one another and customers, in order to manage the networks more efficiently and minimise whole system costs". It also requires DNOs to make efficient decisions by informed consideration of the full range of solutions available and emphasises that there must be mechanisms for transmission and distribution coordination.

The report also suggests that the benefits of more flexible networks could be as much as £40bn by 2050, with part of that benefit coming from using markets in flexibility services to avoid traditional reinforcement where suitable.

Avoiding the cost and disruption associated with installing assets that might only be required for short periods of time during a limited part of the year, alongside the potential to connect customers faster without reinforcement, is generally accepted to be desirable. However, DNOs are not yet in a position to implement flexibility services as business as usual.

There have been a number of innovation projects that have increased our understanding of flexibility services such as Smarter Networks Services, FALCON and Low Carbon London. We have learned about what makes customers willing and able to provide services, different options for commercial structures, service reliability, price sensitivity, or different forms of enabling technology, for example. However, the various projects have, rightfully, focused on individual niche areas of investigation and there are still some gaps in our knowledge in terms of how we bring the various systems together. So, simply scaling up the existing projects would not result in a DSO transition. While the gaps could eventually be filled by further smaller scale individual projects, and each DNO could develop their existing trial systems for business-wide implementation, that approach would most likely be slow and would result in many DNO specific functions and interfaces that would be difficult for the TSO National Grid, aggregators, and suppliers to support. Neither are there existing commercial software products on the market for DNOs that would enable DSO functionality.

In short, while work is progressing towards an agreed template for enabling flexibility services to be introduced into DNOs business as usual, including standardising the functions to be performed and the interactions with third parties, this needs finalising before developing the tools for implementation. This is what the EFFS project planned to deliver. The aim was to confirm the functionality required of DSOs, consider the technical options for delivering that functionality and test a technical implementation in practice. This could then enable a speedier, simpler DSO transition maximising the benefits of flexibility services.

The aim of EFFS, therefore, was to provide DNOs with a system that can support the functions of a DSO via the following objectives:

1. Enhancing the output of the Energy Networks Association (ENA) Open Networks project, looking at the high-level functions a DSO must perform, providing a detailed specification of the new functions validated by stakeholders, and the inclusion of specifications for data exchange.
2. Determining the optimum technical implementation to support those new functions.

3. Creating and testing that technical implementation by developing software and integrating hardware as required.
4. Using and testing the technical implementation, which will involve modelling the impact of flexibility services. As well as proving the system, this testing phase will create learning relevant to forecasting the likely benefits of flexibility services and the impact of changing network planning standards.

Meeting these aims was to result in a proven, workable technical solution, and provide a set of blueprints, best practice guides and learning from which DNOs can create their own technical implementations that meet the same standards or embark on their own product procurements if that would provide better value for money. Streamlining the specification, design and testing work for these new tools will reduce the time and cost for DSO transition, thereby accelerating the benefits from flexibility services.

EFFS fits within the TRANSITION, EFFS and FUSION (TEF) collaboration. This is made up of three NIC projects which began in 2018 and each looks at aspects of the DSO transition with differing aims and areas of focus. In the Project Directions issued by Ofgem for TEF, additional conditions were included to reduce the risk of unnecessary duplication, improve delivery efficiency and ensure the three projects deliver complementary learning. TRANSITION is led by Scottish and Southern Electricity Networks and Electricity North West, and FUSION is led by SP Energy Networks.

2. Executive Summary

2.1. Overview

The Electricity Flexibility and Forecasting System (EFFS or “The Project”) project supports the transition from DNO to DSO by specifying and trialling a new system to plan and procure flexibility services in operational timescales. The Project was funded through Ofgem’s Network Innovation Competition (NIC) and had a budget of £3,338,798. EFFS was registered in September 2018 and completed during September 2021.

The Project operationalised its objectives through the creation of four workstreams as depicted in Figure 1 below.

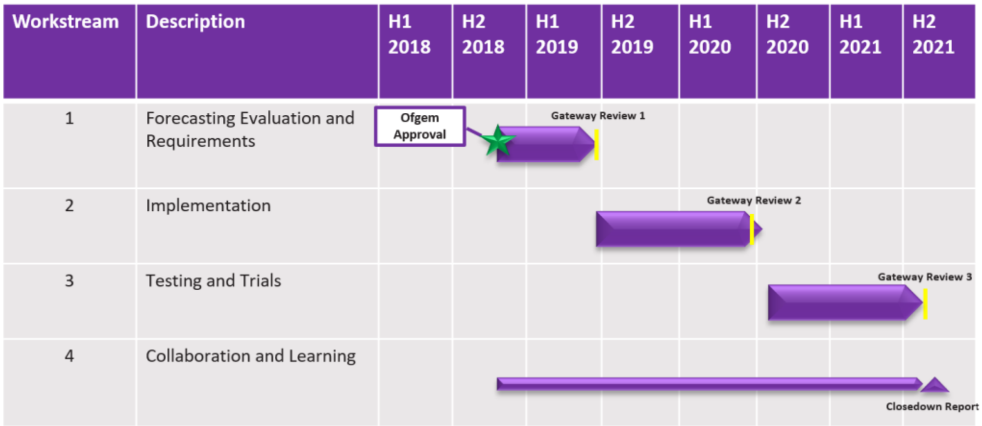

Figure 1: EFFS Timeline

EFFS completed a 24-week trial, from February 2021 to July 2021, in the WPD South West licence area, specifically in the areas surrounding Exeter and Plymouth. The trials demonstrated that the software and interfaces function as intended to support flexibility forecasting functionality. The trials demonstrated that the EFFS solution can forecast flexibility requirements over various time frames and act on these requirements by communicating with various flexibility service platforms. The software was also stress tested via theoretical exercises for conditions that cannot be reasonably recreated as part of a physical trial. The exercises simulated potential energy scenarios for 2030 with much higher volumes of connected generation, more challenging load profiles reflecting future levels of electric vehicles and heat pumps, and greater availability of flexibility services.

Key stakeholders for the trials were:

- **Ofgem** – Project sponsor.
- **Western Power Distribution** – Network licensee accountable for the EFFS trial.
- **AMT-SYBEX** – Trialling of Networkflow (key features: forecasting, optimisation and scheduling).
- **Power Systems Consultants UK Ltd** (PSC) – Trialling of EFFS Tool (key features: data cleansing and power flow analysis).
- **National Grid Electricity System Operator** – Engagement in conflict avoidance and trial interface activities.
- **Centrica Business Solutions – Cornwall Local Energy Market (CLEM)** – Market platform / flexibility service provider.
- **EDF Energy Customers Ltd** – Market platform / flexibility service provider.

2.2. Scope

The aim of EFFS was to provide DNOs with a proven system for flexibility forecasting management that could support the functions of a DSO via the following objectives:

1. Enhancing the output of the ENA Open Networks project, looking at the high-level functions a DSO must perform, providing a detailed specification of the new functions validated by stakeholders, and the inclusion of specifications for data exchange.
2. Determining the optimum technical implementation to support those new functions.
3. Creating and testing that technical implementation by developing software and integrating hardware as required.
4. Using and testing the technical implementation, which will involve modelling the impact of flexibility services. As well as proving the system, this testing phase will create learning relevant to forecasting the likely benefits of flexibility services and the impact of changing network planning standards.

This aimed to result in a set of blueprints, best practice guides and other learning from which DNOs can create their own technical implementations that meet the same standards or embark on their own product procurements if that would provide better value for money. Streamlining the specification, design, and testing work for these new tools will reduce the time and cost for DSO transition, thereby accelerating the benefits from flexibility services. Key functions required for the system included:

- Create weather adjusted forecasts for load and generation at different timeframes to determine the nature, duration and frequency of expected network constraints.
- Model how constraints can be managed, using either flexibility services or existing network solutions.
- Determine the optimum way to resolve predicted constraints which will involve selecting the most effective mix of network technology and flexibility interventions.
- Communicate flexibility services requirements to the market and creating an optimised set of services from those available.
- Execute flexibility services in an optimal way.
- Share information with interested parties to avoid conflicts in flexibility service use.
- Optimise the use of DNO controlled assets across multiple services.
- Support analytics and reporting.

2.3. Outcomes

The Project has completed its lifecycle to time and budget. It has met its four objectives and completed the ten Project deliverables as required in the Project Direction. Despite operational difficulties and impacts on data due to the COVID-19 pandemic, EFFS has delivered substantial documentation and learning for WPD and other DNOs to utilise in their DSO transition journey.

2.4. Objectives

The aim of EFFS was to provide DNOs with a system that can support new flexibility forecasting functions of a DSO via the objectives shown in Table 1:

Table 1 - Project Objectives

No.	Objective	Status
1	Enhancing the output of the Energy Networks Association (ENA) Open Networks project, looking at the high-level functions a DSO must perform, providing a detailed specification of the new functions validated by stakeholders, and the inclusion of specifications for data exchange.	√
2	Determining the optimum technical implementation to support those new functions.	√
3	Creating and testing that technical implementation by implementing suitable software and integrating hardware as required.	√
4	Using and testing the technical implementation, which will involve modelling the impact of flexibility services.	√

2.5. Project Deliverables

All Project Deliverables have been completed. Please see Table 2 for details of these:

Table 2 - Project Deliverables

FSP	Project Direction	Project Deliverable	Evidence	Status
9.1.1	PD-1	Mobilisation Exit Report	A mobilisation exit report will be produced, including evidence of: • Academic partner tender accepted; • Collaboration agreements signed; • Detailed plan with breakdown by Project workstream and milestones; • Project staff mobilised; • Workplaces set up Governance structure in place; • Project Mandate/Charter Agreed; • Project Initiation Document signed off; • Co-ordination plan developed with any other successful DSO related NIC bid to minimise overlap.	√
9.1.2	PD-2	Output from the forecasting and conflict avoidance	Publication of report showing forecasting and conflict avoidance options evaluated and selected options. Presentations at conferences and workshops to disseminate output. Conflict avoidance plan.	√

9.1.3	PD-3	Development of requirements specification for DSO functionality	Production of requirements specification document outlining for DSO functionality, common protocols and approach to supporting these functionalities. ENA and stakeholder collaboration strategy document (delivered a fixed period of time following publishing of ENA workshop output). *Letters of support from key Project partners and stakeholders (delivered as email evidence with no letters of support available).*	✓
9.1.4	PD-4	Development of EFFS Design Specification document	Production of set of Design models and documents outlining specific EFFS functionality and approach to delivering this functionality. Report detailing review of functional specification document at key stages.	✓
9.1.5	PD-5	Implementation and System Delivery	Build and delivery of the completed EFFS system, including technical design package release, deployment and configuration, and system handover.	✓
9.1.6	PD-6	Completion of on-site system testing	Test report demonstrating completion of on-site testing to required standards; includes integration, user acceptance, operational and performance testing. Supply of additional supporting documentation evidencing this claim, to include test plans, scripts, exit reports and screenshots. Report detailing completed user training.	✓
9.1.7	PD-7	Trials design and preparation	Strategy document outlining trials approach and methodology, detailing approach to plant, system operations, supplier / aggregator and tandem operations trials. Co-operation plan showing how duplication with other DSO NIC projects has been avoided and, if possible, how testing between projects will be carried out.	✓
9.1.8	PD-8	Trials – execution and knowledge capture	Completion report demonstrating outcomes of trial phases alongside test scripts, exit reports etc. Letter of support from external stakeholders and partners confirming completion of project trial phase and acceptance of results.	✓
9.1.9	PD-9	Gateway reviews	Delivery of gateway report at the end of Workstream 1, Workstream 2 and Workstream 3, detailing progress against the project benefits and costs.	✓
9.1.10	PD-10	Knowledge Dissemination Co-ordinate with any other DSO related NIC projects and comply with knowledge transfer requirements of the Governance Document	1. Plan for co-ordinated knowledge dissemination with other DSO NIC projects. 2. Annual Project Progress Reports which comply with the requirements of the Governance Document. 3. Completed Closedown Report which complies with the requirements of the Governance Document. 4. Evidence of attendance and participation in the Annual Conference as described in the Governance Document.	✓

2.6. Learning Derived by Project and Methods

The primary learning from the Project has stemmed from the development of a new, innovative and practical system to forecast flexibility requirements on the network and to plan and procure flexibility services. The EFFS system design documents have provided the industry with a blueprint for this, and the end-to-end operation of the system is evidenced through the Project's testing and trial exit reports. The project learning has supported the TEF Projects in devising their own systems and trials, as well as feeding into the Open Networks Project.

A number of secondary learnings were also developed, including learning on various methods of forecasting and its outputs, where forecasting at lower voltage levels appear most appropriate to feed into power flow analysis, and primary substations facilitate a much higher degree of forecasting accuracy than other equipment types.
Learning on engagement with flexibility platforms demonstrated reliance on set timings to ensure a fair competition between providers, and currently the flexibility platforms are not yet interoperable in terms of service types and signals, so data exchange must be adaptable for use across multiple platforms, with minor adjustments to associated business processes. This demonstrates that a uniform set of interfaces to flexibility platforms and interoperability in the industry is achievable.

Further details on the learning developed within the Project can be found within sections 9 and 10.

3. Details of the Work Carried out

3.1. Overview

This section provides a summary of the work carried out for each of the Methods that were implemented in the EFFS Project, before moving on to a more detailed look at each of the aspects carried out.

Requirement Determination and System Design

The Project undertook a Requirements and Design phase for the overall end to end EFFS solution. This was key to determining the solution required for the EFFS trial and how the DSO would operate using ENA Open Networks World B. Using the model developed by Open Networks World B the Project designed a system to match the operation of this operating model. A series of workshops took place and involved running a series of workshops with business stakeholders across WPD and its Project partners. The Project structured the requirements and design into eight key areas:

- **Forecasting** – Covered the Time Series (TS) data cleansing and forecasting demand and generation process;
- **Capacity Engine** – Covered the power system analysis process and constraint identification process;
- **Service Management** – Covered the configuration and setup of flexibility service types;
- **Optimisation** – Covered the procurement optimisation and selection process;
- **Scheduling** – Covered the scheduling of flexibility after selection;
- **Conflict Avoidance and Synergy Identification** – Covered the coordination and conflict avoidance between the DSO and TSO;
- **Market Interface** – Covered the interfaces required for market platforms to communicate during the publishing and selection of flexibility services; and
- **Reporting** – Covered the core reporting requirements required for the DSO to operate.

The output of work created an overall system architecture shown below in Figure 2. All the core functions shown below are detailed in the System Design Summary Report[1] :

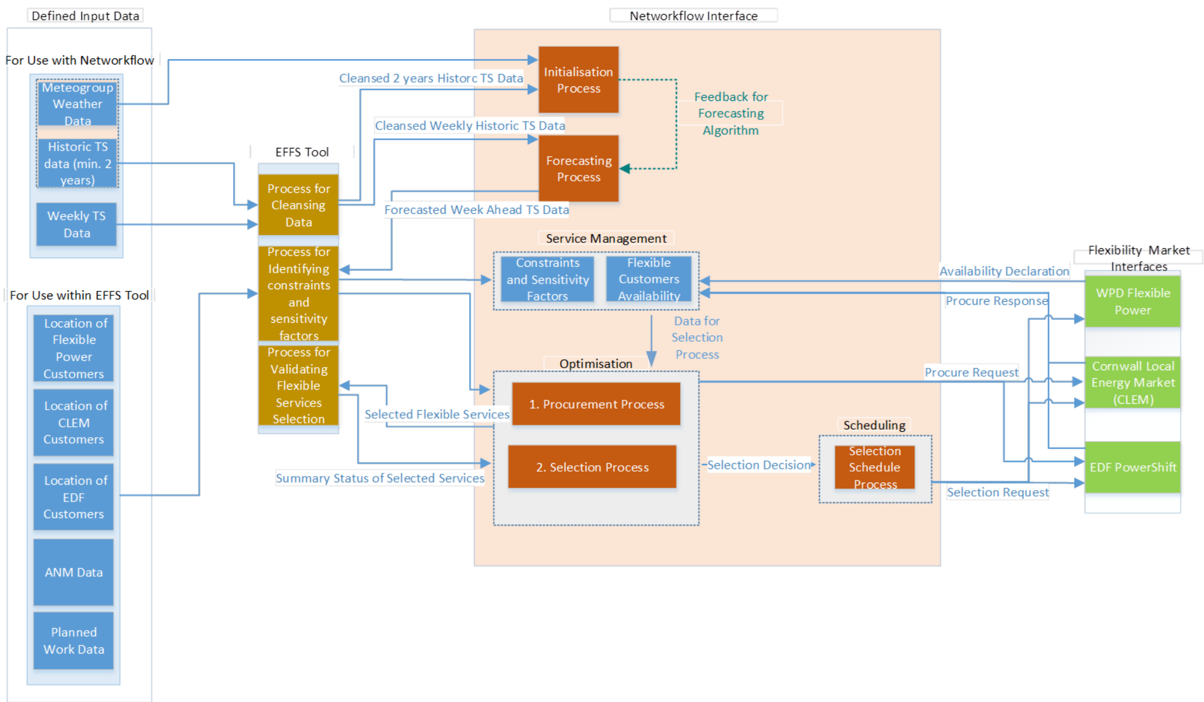

Figure 2: EFFS Solution Overview

[1] Found at https://www.westernpower.co.uk/downloads-view-reciteme/64093

System Development

Upon completion of the system requirements and design, the respective Project parties undertook development to either develop, amend, or reconfigure their existing solutions to support the trials. AMT-SYBEX Networkflow product was reconfigured for the inclusion of additional optimisation parameters. Power Systems Consultants (PSC) were then contracted mid-project to develop the EFFS tool, a python based tool that carried out data cleansing, constraint analysis using an interface with PSS®E (Siemens Power System Simulation for Engineers software), and flexibility service selection validation.

System Test

The system testing phase took place from October 2020 to January 2021. The Project created an On-site Test Approach to align stakeholders for the phase, including details on approach, entry/exit criteria, and roles and responsibilities. A test plan and workbook were also created for each stage of the testing. The onsite testing phase was structured into two iterative test stages: System Integration Testing (SIT) and User Acceptance Testing (UAT). SIT validated that the software components described above could interact as required on WPD infrastructure.

The scope focused on data interfaces, using the AMT-SYBEX Networkflow product and the EFFS Tool developed by PSC. The testing was split into 9 sub-modules. Figure 3 below displays an overview of the interfaces tested during SIT. Each module was first tested separately using real or simulated input data. The output from each module was compared against the expected results as per original design documentation. Finally, a full end-to-end test cycle was performed on the system.

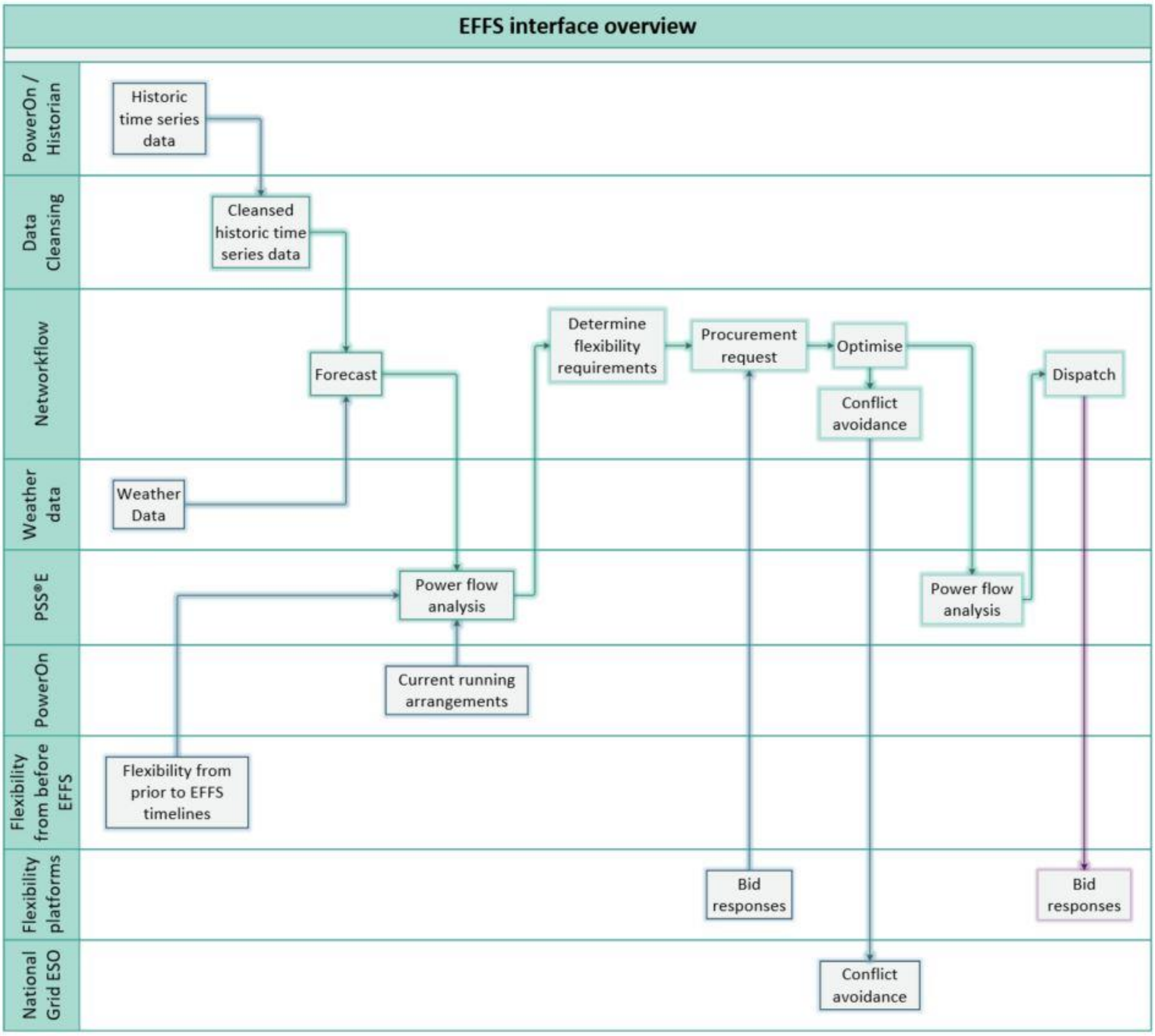

Figure 3: EFFS Data Interfaces

After successful completion of SIT, UAT commenced and was split into a front-end user and back-end user testing. In UAT data input was replicated to determine constraints and whether flexibility services would be required. The users then performed the back-end user testing to validate the solution would select the appropriate flexibility service to resolve a constraint.

Trials Methodology

A 24 week trial was carried out during the EFFS project to test the system developed. This included trialling all areas of the system, including data cleansing, forecasting, constraint analysis and service selection and validation, before demonstrating how this process flows as an end-to-end system. This trials phase spanned from December 2020 through to July 2021.

The purpose of the trials phase was to demonstrate that the software and interfaces developed to support the relevant DSO functionality work and that the forecasting and co-ordination elements function as intended. As such the process enabled regular and recurring use of the whole system, and the interface between the EFFS solutions and multiple external platforms was carried out.

The 24-week trial was split into four sequential phases:

1) Pre-trials: 2 weeks of preparatory work for completion of pre-requisite activities, including software deployments, pipe cleaning and data cleansing;
2) Initiation: 2 weeks of running the system without manual intervention;
3) Operation: 18 weeks of operational running of the EFFS solution, involving real-life scenarios and desktop exercises; and
4) Closedown: 2 weeks of closedown operation of the EFFS solution.

3.2. Forecasting

Overview

Forecasting can be used to predict the future distribution network load and generation, with the results primarily used to improve decision-making and planning activities by the DNO. Forecasts that are produced almost always incorporate some degree of error, however, it is beneficial to have this information produced by the forecast than to plan in ignorance. With the transition to DSO, the operation of the network must work with tighter margins to delay the costs of reinforcement. As such where the DSO forecasts a constraint, such as a thermal constraint where the demand exceeds the tolerance of the substation, flexibility can be procured to shave the peak in demand and thus delaying the cost of reinforcement.

Algorithm Selection

At the start of the Project, a procurement process was undertaken to determine a suitable forecasting algorithm provider, with Smart Grid Solutions (SGS) being selected. As part of their investigatory work into forecast selection, SGS looked at multiple areas of investigation before proceeding to model evaluation. Namely looking at what constitutes a good algorithm, i.e. one that can predict with factors such as seasonality or with levelling. Then, the data was assessed to determine its quality and usefulness to identify outliers or missing values. Data cleansing was performed to ensure that it was suitable for training and evaluating the algorithms.

Two types of forecasting method were considered: classical statistical and artificial intelligence. Within these methods, ten algorithms were assessed and the following were shortlisted:

- **Autoregressive Integrative Moving Average (ARIMA)** – This is the classical statistical technique used quite commonly for time series analysis. This approach takes historical data and makes predictions using an autoregressive technique.
- **Long-Short-Term Memory (LSTM)** – A deep learning technique that uses artificial neural networks to predict time series data but is not as commonly used as other techniques.
- **Extreme Gradient Boosting (XGBoost)** – This is a supervised machine learning decision tree algorithm that is highly respected in the field of machine learning for numerous problems such as regression and classification. This approach creates decision trees and learns from weaker trees, iterating until it produces the outcome of a strong tree.

Throughout the algorithm selection process, SGS created and tested these forecasting methods[2] and recommended the use of the XGBoost algorithm due to its comparative accuracy to the other methods, and its easy adaptability for automation[3]. The other techniques may have produced better accuracy, though this would have come at a significant cost. Largely for two main reasons[2]:

1. It takes longer to tune and train the other techniques, particularly the LSTM models; and
2. Significant data science resources are required to iterate and improve model performance, making it a lower degree of automation.

The figures below show an example of the best case (left) and worse case (right) predictions for a substation using XGBoost undertaken during the quality assurance phase of the forecast evaluation.

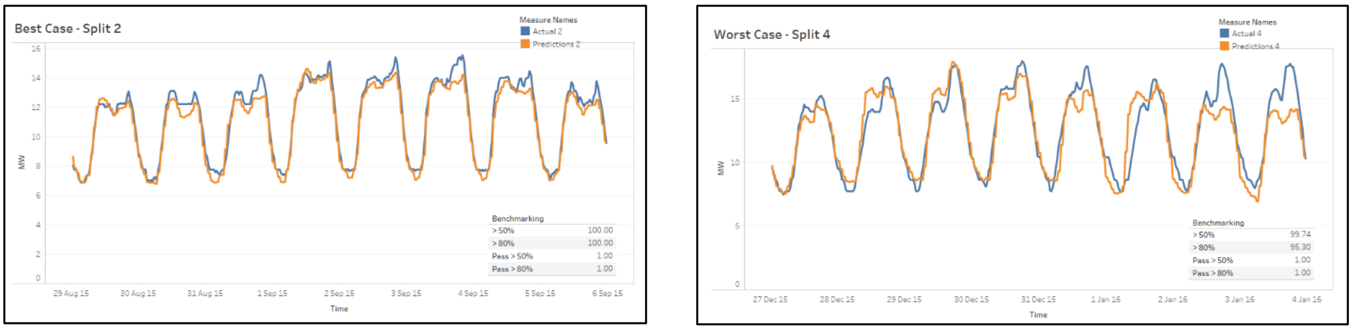

Figure 4: SGS Output of forecast accuracy evaluation for the best and worse predictions by XGBoost

Once the forecasting algorithm was built and tested, it was then instantiated into Networkflow. As part of this process, the Jupyter notebooks were converted into productionised python code that could run within the software.

Forecast Configuration

During the algorithm selection process, several features and tuning parameters were identified as key to the tuning and the training of the forecast model. XGBoost has many parameters to train the model. However, the key parameters that impacted the model's performance were found to be the number of decision trees and the size of the trees.

The following forecast features were deemed relevant across all demand and generation for time series forecasting:

- Hour
- Day of Week
- Quarter
- Month
- Year
- Day of Year
- Day of Month
- Week of Year

During this phase of the Project, it was advised the most optimal tuning and training times should be as follows:

- **Tuning** – One Year:
  - 48 Weeks Tuning
  - 4 Weeks Testing
- **Training –** One Year:
  - 51 Weeks Training
  - 1 Week Testing

The above was the baseline configuration the Project used to forecast at different time horizons during the trials.

[2] See Forecasting Validation Testing Report - Section 3.2, found at https://www.westernpower.co.uk/downloads-view/46990
[3] See Forecasting Evaluation Report - Section 8.2, found at https://www.westernpower.co.uk/downloads-view-reciteme/43210

Forecast Approach

The Project produced forecasts at 21 primary substations and 7 generation sites (4 Short Term Operating Reserve (STOR), 2 Solar and 1 Multi-Fuel Generator). These sites were forecasted throughout the trial at the following time horizons:

- Six Months Ahead
- Month Ahead
- Two Weeks Ahead
- Week Ahead
- Day Ahead

The forecast horizons were scoped and agreed upon as part of the Project's design phase. However, during the trials, a new time horizon, the two weeks ahead, was deemed useful. It became apparent operationally that the two week ahead forecast creation was required due to the procurement process commencing the week before the flexibility service was due to start. Flexibility platforms required bids to be confirmed the Thursday before the start of the following week (the Monday). Therefore, the process followed during the trial was:

- **Monday** – Data cleansing, run forecasting and run powerflow analysis.
- **Tuesday** – Create services from powerflow analysis and service requirements issued to market platforms.
- **Wednesday** – Receive market platform responses.
- **Thursday** – Run optimisation, run powerflow analysis validation and confirm bids for service commencing the following Monday.

Forecast Accuracy

When the forecast algorithm was developed, the MAPE (Mean Absolute Percentage Error) was chosen to be a standard[4] accuracy metric to be used. MAPE is a measure of how accurate a forecasting system is. This figure is presented as a percentage and can be calculated using the following equation:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|$$

Where:

- n is the number of points
- A_t is the actual value
- F_t is the forecast value

However, due to close to and zero values in the data, predominantly found in generation sites as they do not always produce output, it was identified that the MAPE values can cause an error in the program due to a division of zero in the data.

Therefore, a default value of 200% was used when the software solution had an actual or predicted value that was a zero to prevent it from generating an error and producing no metric. In addition, MAPE values can produce infinite or undefined percentages when the actual values are close to zero. To resolve this, the MAE (Mean Absolute Error) was also used to evaluate the true error on sites and acted as an additional measure of accuracy. This was more effective as it is not sensitive to zeros, or values close to zero, and gives a good indication of the forecast accuracy in comparison to the MAPE. For example, if a site recorded an average of 10MW per half-hour (HH), then an MAE of 0.5 would represent half an MW of error per HH, representing a 5% error reflective of the size of the site.

Table 3 shows a summary of the accuracy found during the Project trials. This is shown in the accuracy metrics used during the trial period.

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[4] See Forecasting Validation Testing Report - Section 4.3, found at https://www.westernpower.co.uk/downloads-view/46990

Table 3 - Forecasting Performance Summary

Forecast type	MAPE	MAE
Overall MAPE Across All Channels and Forecast Types	52.18%	0.67
Overall MAPE MW Across All Forecast Types	41.93%	1.11
Overall MAPE MVAr Across All Forecast Types	62.40%	0.22

Forecasting Horizon Comparison

Forecasting accuracy has been compared over multiple time horizons during the trial period. The aim of this was to provide learning on what is the best fit horizon to use for forecasting, demonstrate where the value lies in carrying out forecasting further ahead of time, and validate all time horizons against each other's outputs. Table 4 below shows an example of the average primary substation accuracy findings for this process.

Table 4 – Average Primary Substation Time-Horizon Performance across all Trial Primary Substation Sites

Accuracy									
Equipment Type	Channel Type	One Week Ahead		Two Weeks Ahead		One Month Ahead		Six Months Ahead	
		MAPE	MAE	MAPE	MAE	MAPE	MAE	MAPE	MAE
Primary Substation	MW	21.49%	0.86	21.85%	0.88	19.76%	0.93	21.07%	0.93
	MVAR	47.70%	0.23	47.58%	0.23	54.51%	0.22	52.21%	0.21

2020 Lockdown Impact on Forecast Accuracy

The UK, like much of the world, commenced lengthy periods of lockdown from March 2020 due to COVID-19. This greatly reduced demand on most of the energy networks, particularly where there is a high penetration of commercial and industrial use. When the forecast algorithm was designed for the trials, it was never envisaged that the world would enter such an unprecedented situation, and nor could the scope of the Project have dealt with developing an algorithm to meet this eventuality.

Therefore, the Project, when trialling the forecasting algorithm, could only work with the available data. The approach was to feed the algorithm the previous two years of historical data for tuning and training. During the trial, it was noted that the forecasts were poor from the end of March until June. After analysis, the periods of poor predictions coincided with the UK lockdown period in 2020 where the demand trend was reducing, in addition, in May 2021 demand was higher than previous or 'normal' years due to the wet weather impacting the country at that time and particularly the trial area in the southwest. This finding led to the learning that for successful forecasting to be carried out, weather data would be usefully applied to mitigate the impact of any extreme weather conditions.

Further Forecast Evaluation Work

The Project explored further forecasting evaluation using engineering models and weather data, in addition to sampling another algorithm. SGS undertook an evaluation of engineering models and weather data and during the trial phase the Project sampled XGBoost against an additional decision tree algorithm.

XGBoost vs Engineering Models and Inclusion of Weather Data

The conclusion of the delivery of the XGBoost algorithm, stated that:

- Incorporation of weather forecast data as a feature of the XGBoost could improve MW and MVAr forecast; and
- Using weather forecasts and applying them to engineering models may perform better than machine learning models under certain conditions.

SGS explored the performance of the XGBoost model with the inclusion of weather forecast data and the performance of engineering models of directly connected generation sites to the WPD network with weather forecast data. The XGBoost algorithm was updated to include forecast weather data and was evaluated against the engineering models. The engineering models were developed using open-source python libraries to forecast wind and solar generation.

Following this evaluation SGS concluded from the analysis of the performance of the engineering models for both wind and PV that:

- PV summer models perform well relative to winter;
- Wind models perform well where coefficients are well-tuned;
- Peak prediction was good across well-tuned (coefficient fit) wind models and summer PV models; and
- All models will benefit from improved coefficient tuning. Herein lies the issue with operationalising these models. This may be required on a site-by-site basis.

For the XGBoost vs engineering models' comparisons were made for each model against each other. ML Performs better generally, but engineering models perform better at peak prediction. The following should be noted:

- XGBoost performs better in general because site operational coefficients are embedded in XGBoost decision trees, whereas EM model a baseline coefficient applied across the board. XGBoost tunes itself from the data;
- This is supported by improved behaviour where coefficients are more accurate;
- Engineering models Peak prediction better than XGBoost. XGBoost is trying to minimise error across the whole time series and not just the peaks and appears to smooth out some peaks;
- Once site engineering models are tuned to site nuances, the prior operation is not relevant. The prior erroneous operation, due to site running issues, could get embedded as they do in the XGBoost model if those periods are inadvertently used for training; and
- It is easier to tune engineering models to peak, than to site features (embedded in XGBoost decision tree weightings) between zero and peak.

Therefore, the two models provide insight on the general, and peak behaviour of site behaviour. This suggests both model types could be used together to provide a spread of scenarios bounded by model predictions.

Decision Tree Algorithm

During the trials, the Project sampled an alternative forecasting technique for two network nodes that used a Microsoft Excel based decision tree algorithm solution to derive further learning. This alternative tool used the time series data as features but also includes historical and forecast weather data and was trained on one month worth of data to make a prediction.

The period sampled was during the first lockdown UK lockdown. XGBoost being trained on one year worth of data made poor predictions as described above due to the training data set. However, sampling the alternative solution by training the data with a month's worth of data showed an improvement in forecast prediction.

This process demonstrated that extreme events, such as nationwide lockdowns, impact training data and over a long period of time this would generate low accuracy. Using shorter time periods for training data to avoid large scale trends can achieve greater accuracy, and a tools inclusion of weather data within forecasting can further mitigate this impact.

3.3. Constraint Analysis and Data Cleansing

Overview

During the build phase, the Project undertook procurement for a solution to manage the power flow analysis outlined in the Capacity Engine function. The task was awarded to PSC who would carry out the development of a power flow analysis interface, known as the EFFS Tool, to automate power flow studies within Power System Simulator for Engineering (PSS®E).

Solution Development

The EFFS tool was developed in Python for compatibility with PSS®E as the selected power system analysis tool. To enable ease of interaction between the various stages of the EFFS processing, a graphical user interface (GUI) was also developed for improved ease of use. The build phase consisted of several activities as detailed below:

- Cleansing of historic weekly time series generation and demand data for analysis by the Networkflow forecasting engine;
- Receipt of week-ahead forecast generation and demand data and setting up the PSS®E model;
- Contingency identification in the power system model that includes analysis of planned outages and circuit outages;
- Running of time series and contingency analysis to identify system constraints;
- Identification of flexibility services that can resolve constraints; and
- Outputting required flexibility services and associated sensitivity factors.

Trials

Data Processing

A data processing system was in place within the EFFS tool to cleanse and prepare data to be used for forecasting, constraint analysis and flexibility service validation. This system had included the following interactions:

- Exchange of cleansed historic Time Series (TS) data and forecasted TS data;
- Exchange of network constraints and sensitivity factors of flexibility services; and
- Exchange of selection and validation of flexibility services.

This process was utilised during the weekly trial runs and has therefore been tested using a range of data sets with varying network conditions.

The EFFS tool received TS data at two stages during the process carried out. This includes historic TS data from WPD, which is checked and prepared for use for forecasting, and then the forecast TS data which is used for network analysis and simulation.

Forecast Alteration Method

To maximise the testing of the EFFS process carried out within the trial period, a forecast alteration method was developed to ensure constraints were found on the network each week, allowing for demonstration of the procurement and selection of flexibility services.

To ensure that the trials provided value, the forecast demand and generation profiles for each week were adjusted to increase the demand or generation to a level where it would produce a constraint. This was done by identifying assets that could become overloaded during certain contingencies but would also result in at least 1 of the available flexibility services being able to contribute to resolving the constraints. Assets to target were selected in a way that in some instances a single service would be able to contribute and in others, multiple services would be able to contribute to ensuring that optimisation algorithms were also tested.

Figure 5 shows an example of the half-hourly demand profile across a single 33/11 kV transformer within the trial region. The blue line showing the original demand profile and the orange line showing the altered demand profile which now crosses the transformer rating during certain outages on the system. This large alteration is representative of a change made by the python tool but will only be applied to nodes that would not produce a constraint, therefore the overall change to the forecast is smaller than the change shown.

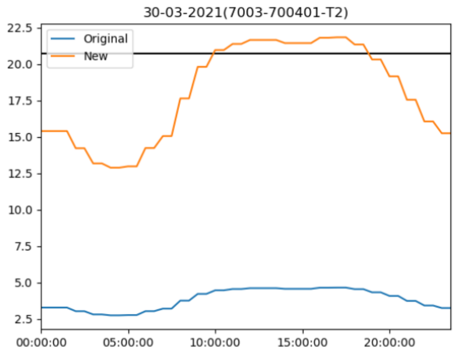


Figure 5: Examples of Time Series Data Quality Output

Constraint analysis was then carried out using both the raw forecast data and the updated forecast data. Where constraints were facilitated, and did not exist within the network, flexibility services were not procured as it was deemed that this procurement would have provided poor value for money for customers.

Constraint Analysis Methods

Within the trial, Constraint Analysis was carried out for each run. This was carried out by the EFFS tool and its interface with PSS®E, using a network model which is updated with load and generation forecast data, planned outage information and active network management (ANM) information. Constraints were identified by the tool checking the analysis results against defined threshold values, to demonstrate where assets are above acceptable load flow conditions in any HH period. Figure *6* demonstrates the tools graphic user interface. This was facilitated using the power flow analysis method outlined in the following section.

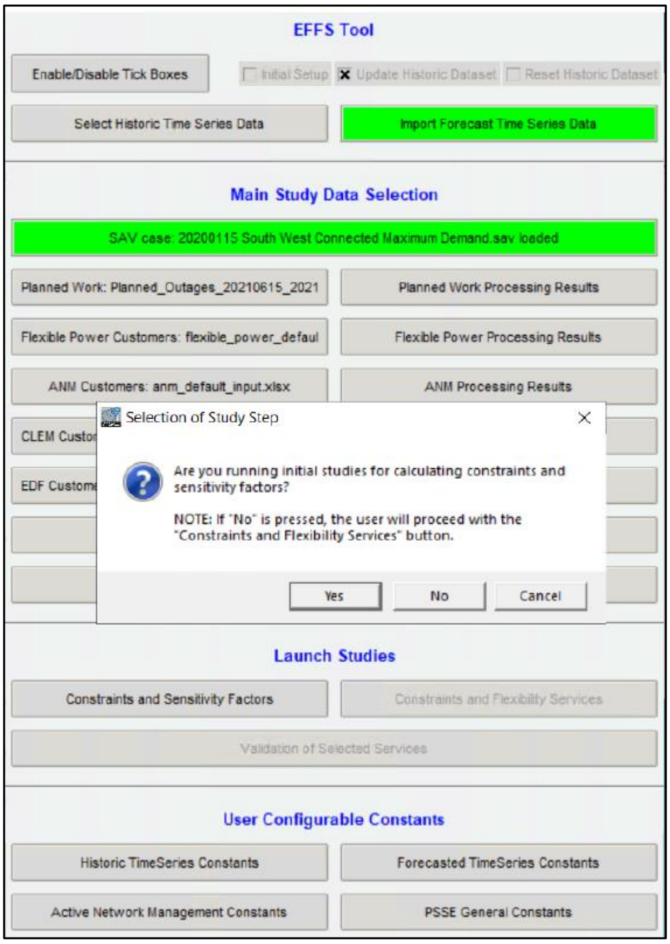


Figure 6: Constraints and Sensitivity Factor Calculation using EFFS Tool

Power Flow Analysis

The EFFS tool ran PSS®E load flow studies utilising forecasted load and generation data for the week ahead in order to identify network constraints and calculate sensitivity factors. In doing this, the tool ran iterative studies for each HH step of the forecasted TS data.

Before running the iterative load flow studies, the tool performed an initial preparation of the PSS®E case by doing the following:

- Removal of existing loads and generators in the regions of interest;
- Mapping of the ANM customers; and
- Mapping of the flexibility platform customers.

Following this, the tool ran a power flow iteration for each HH step and imported forecast data for each substation in the area. The results of this power flow analysis were checked against a user-defined threshold value to identify assets with a loading above the user-defined threshold limit for each HH period and the thermal violation is calculated. In addition to considering the normal running arrangements on the network, the impact of possible outages of network assets were also considered as these may lead to constraint situations that could be resolved with flexibility services.

Calculation of Identified Constraints and Sensitivity Factors

Since the impact of a flexibility service on the constraint is expected to be different for flexibility services located at different locations, sensitivity analysis was performed to quantify the impact that a change in the flexibility services will have on the constraints. Sensitivity factors have been utilised which are effectively ratios that show how much the flexibility service will impact the constraint.

Once the constraints and sensitivity factors were calculated for each HH step and contingency, the 'worst' values calculated were utilised in the next step of the process where the flexibility requirements were calculated, and the selection of flexibility services took place.

3.4. Procurement and Selection of Services

Overview

The Project developed, tested, and trialled a flexibility procurement process which involved receiving constraints from the powerflow analysis performed by the EFFS Tool as described above, before processing within the Networkflow system, and transforming these constraints into services, generated requests and responses to and from market platforms using the interfaces. Flexibility requirements were validated and optimised using an optimisation algorithm to select the most optimal flexibility bid. This was handed off to the EFFS Tool for final validation before confirmation of a flexibility bid was accepted. The trials used the EDF Energy PowerShift Platform and the CLEM Platform to interact with the market. Throughout the trials the Project facilitated creating flexibility bids, communicating these to the platforms, receiving the bids responses, performing optimisation, and submitting the final selection of services.

The Project used a Comma Separated Values (CSV) communication method as defined in the system design[5] consisting of:

- Publish Requirements - DSO to Platform
- Procurement Response – Platform to DSO
- Procurement Selection – DSO to Platform

Service creation

Upon receipt of the constraints from the EFFS Tool, the Networkflow solution would transform the constraints into services required for communication to market platforms. Figure 7 is a screen capture of a list of required services from the trial.

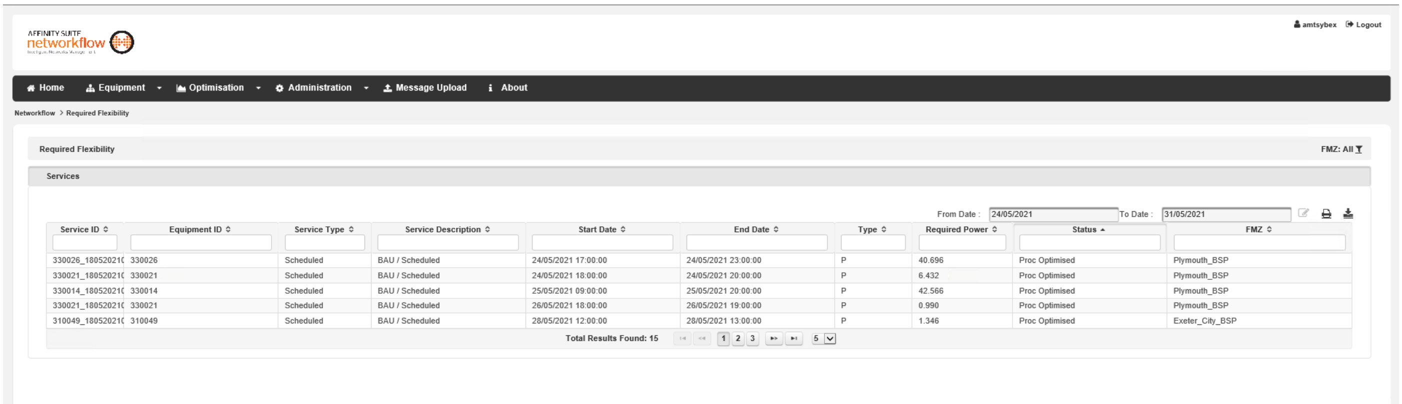
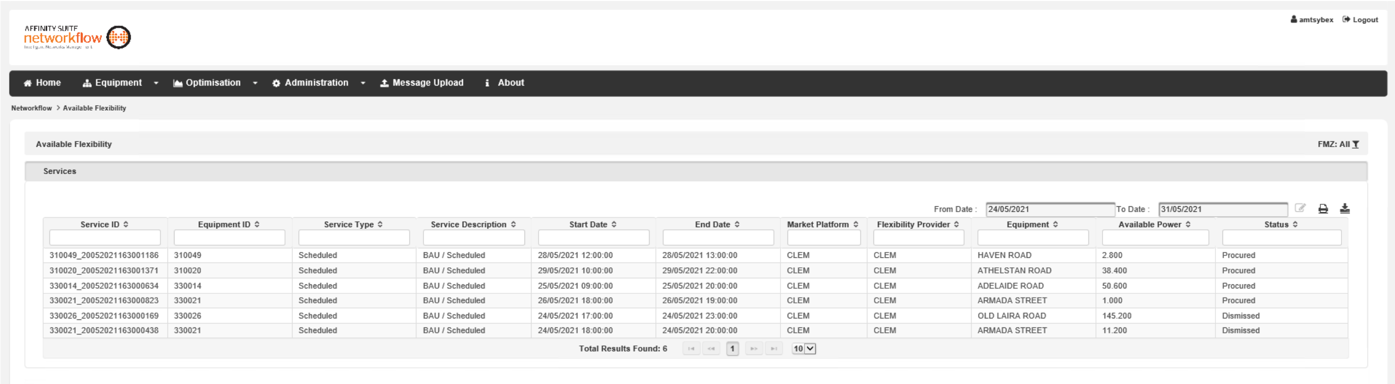


Figure 7: Required Flexibility Services

Procurement Responses

The market platforms responded to service requirements, and these would be captured as available flexibility services to meet the requirements of the required services. Shown in Figure 8 is the list of flexibility bids received for the required flexibility in Figure 7. What can be witnessed is that most of the bids were accepted but the others dismissed, this was because the other bids would have caused another constraint on the network and were best not included.

[5] See System Design: Market Interface, found at https://www.westernpower.co.uk/downloads-view-reciteme/64096



Service ID	Equipment ID	Service Type	Service Description	Start Date	End Date	Market Platform	Flexibility Provider	Equipment	Available Power	Status
310049_20052021163001186	310049	Scheduled	BAU / Scheduled	28/05/2021 12:00:00	28/05/2021 13:00:00	CLEM	CLEM	HAVEN ROAD	2.800	Procured
310020_20052021163001371	310020	Scheduled	BAU / Scheduled	29/05/2021 10:00:00	29/05/2021 22:00:00	CLEM	CLEM	ATHELSTAN ROAD	38.400	Procured
330014_20052021163000634	330014	Scheduled	BAU / Scheduled	25/05/2021 09:00:00	25/05/2021 20:00:00	CLEM	CLEM	ADELAIDE ROAD	50.600	Procured
330021_20052021163000823	330021	Scheduled	BAU / Scheduled	26/05/2021 18:00:00	26/05/2021 19:00:00	CLEM	CLEM	ARMADA STREET	1.000	Procured
330026_20052021163000169	330026	Scheduled	BAU / Scheduled	24/05/2021 17:00:00	24/05/2021 23:00:00	CLEM	CLEM	OLD LAIRA ROAD	145.200	Dismissed
330021_20052021163000438	330021	Scheduled	BAU / Scheduled	24/05/2021 18:00:00	24/05/2021 20:00:00	CLEM	CLEM	ARMADA STREET	11.200	Dismissed

Total Results Found: 6

Figure 8: Available Flex Services

Optimisation

Optimisation is the process whereby all the required services are evaluated for available flexibility services and a selection of services is made on several criteria. Ultimately selecting the lowest cost bid to meet the requirement based on price and reliability. The optimisation process was run each week throughout the trials. However, due to lack of market liquidity, it was very difficult to fully test largely because not every substation that showed a constraint had an available service and most sites only had one service available. Given the lack of services available the Project chose to optimise based on the lowest price.

Figure 9 shows the result of a service that has been optimised with the requirements highlighted in orange and the market bid in green.

Figure 9: Optimisation Selection

The optimisation performed well in terms of timings and functionally with the lowest cost service always selected within a few seconds. However, in the stress testing phase of the Project, the optimisation was fully tested by simulating market liquidity. Six bids were simulated per constraint and it always chose the most optimal service based on price and reliability. Three of the optimisation scenarios are shown in the following subsections:

Market Platform

In this scenario we focused on using the optimisation based on market platform. In Table 5 below, there are three bids, two from a platform that less reliable. Note that bid one and three are from a less reliable platforms than bid two, although the other bids were cheaper, bid two was selected due to the reliability factor impacting the bid.

Using an indicative scoring method, the optimisation selected the most optimal bid as it has selected the lowest cost bid that has the highest reliability.

Table 5 - Optimisation Selection by Platform

Bid No.	Utilisation Payment (£)	Total Cost of MW for Service (£)	Total Bid Cost (£)	Market Platform Reliability	Weighting Factor	Provider Reliability	Weighting Factor	Asset Reliability	Score
1	83.28	60.8	144.08	10%	100%	100%	100%	100%	0.0031
2	127.02	52.94	179.96	100%	100%	100%	100%	100%	0.0003
3	75.22	85.45	160.67	10%	100%	100%	100%	100%	0.0043

Flexibility Provider

In this scenario we focused on using the optimisation based on flexibility provider. In Table 6 below, there are three bids, two of the bids are of the same price and another at a higher price. Note that all the bids are from less reliable platform, however, bid one has a less reliable flexibility provider, whereas bid two and three do not.

Using an indicative scoring method, the optimisation selected the most optimal bid as it has selected the lowest cost bid that has the highest reliability.

Table 6 - Optimisation Selection by Provider

Bid	Utilisation Payment (£)	Total Cost of MW for Service (£)	Total Bid Cost (£)	Market Platform Reliability	Weighting Factor	Provider Reliability	Weighting Factor	Asset Reliability	Score
1	£77.03	£144.88	£221.91	10%	100%	10%	100%	100%	0.3991
2	£77.03	£144.88	£221.91	10%	100%	100%	100%	100%	0.0399
3	£53.46	£171.39	£224.85	10%	100%	100%	100%	100%	0.0465

Asset Reliability

In this scenario we focused on using the optimisation based on asset. In Table 7, there are three bids, bid one and three are from more reliable assets, whereas bid two is not. Using an indicative scoring method, the optimisation selected the most optimal bid as it has selected the lowest cost bid that has the highest reliability. We can see that the total cost of the service on bid two is the cheapest but the reliability effects its score and choses the next cheapest reliable service.

Table 7 - Optimisation Selection by Asset

Bid	Utilisation Payment (£)	Total Cost of MW for Service (£)	Total Bid Cost (£)	Market Platform Reliability	Weighting Factor	Provider Reliability	Weighting Factor	Asset Reliability	Score
1	110.91	205.8	316.71	100%	100%	100%	100%	100%	0.056
2	92.83	121.78	214.61	100%	100%	100%	100%	1%	35.421
3	122.45	184.87	307.32	100%	100%	100%	100%	100%	0.0051

3.5. Platform Integration

To support the trials, EFFS interfaced with Centrica's Cornwall Local Energy Market, EDF Energy's PowerShift platform, and compared outputs with our own FlexiblePower platform.

These platforms offered access to a variety of customers required for the trial phase of EFFS. As the platforms evolved at different times to meet different purposes, they generated separate learnings for each platform rather than being duplicates of each other. Interfacing with multiple platforms allowed for learning around the practical issues for activities such as optimisation and whether the multiple platforms act to facilitate a single open marketplace or act to subdivide the market.

Design

Uniform interfaces to flexibility platforms have yet to be defined at an industry level. Without an agreed standard, EFFS defined its own default set of instructions for communicating with flexibility platforms with the assumption that any flexibility platform integrating to EFFS would use this standard[6] without a requirement to develop customised interfaces for EFFS to interface with platforms. The instructions and associated data items were derived from the service types defined by the ENA ON and the operational procurement, arming and dispatch processes defined by EFFS. In practice, the flexibility platforms EFFS is interacting with are not yet interoperable in terms of service types and signals supported, however, the data exchange developed within EFFS could be used across multiple platforms with slight tweaks to the associated business processes.

Once a requirement for flexibility has been identified, this will be issued to the Flexibility Platform via an agreed mechanism such as an interface. The mechanism includes a series of requests/responses so that participants can bid for periods of flexibility.

Figure 10 is an example of the data exchange and signals agreed during the design phase and implemented during the EFFS trials.

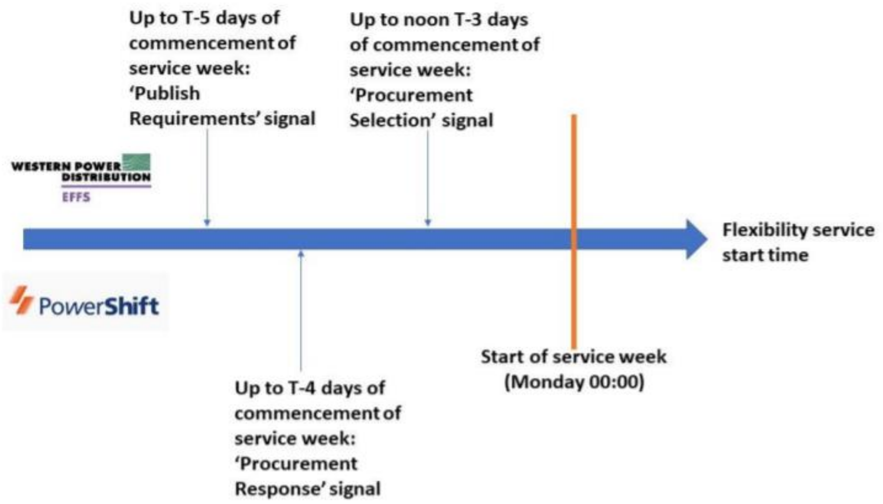


Figure 10: Procurement Timeline

Build / Test / Trials

The successful execution of the EFFS trials validated the principles assumed earlier in the Project: that the data exchange developed within EFFS could be used across multiple platforms with slight tweaks to the associated business processes. This demonstrates that a uniform set of interfaces to flexibility platforms and interoperability is achievable.

[6] See System Design: Market Interface, found at https://www.westernpower.co.uk/downloads-view-reciteme/64096

3.6. Conflict Avoidance

Overview

The Project engaged with the Electricity System Operator (ESO) and other stakeholders throughout the duration of the Project to define and carry out workshops on conflict avoidance processes.

Design

The first output for the Project was the proposed high-level design of how the ESO and DSO would interface to facilitate conflict avoidance and the process to support this. The outputs from these sessions included:

- A proposed process to facilitate conflict avoidance;
- Creation of a list of conflict scenarios;
- Proposed principles on how to resolve conflict.

This work was used as a basis to inform the Primacy work of the Open Networks Project[7], specifically the definition of the below user cases:

- More than one user of flexibility services trying to use the same asset at the same time (regardless of whether they require the same action).
- More than one flexibility service user trying to use the same asset – only if working in opposite directions.
- Different flex service users procuring / dispatching services on different assets that are electrically arranged so that one service negates or partially negates the other.
- DNOs ANM scheme reducing generation constriction (or load restriction on Load ANM scheme in the future) which negates the impact of a flexibility service procured/dispatched by a third party.
- A flex service user (other than DNO) procuring/dispatching a service that results in a capacity threshold being breached on the DNO network, and then causes the DNO to take action (may or may not be flex service) to avoid that threshold.
- A DNO procuring/dispatching a service that results in a capacity threshold being breached at the Grid Supply Point and then causes the ESO a problem.
- The session discussed principles of how to resolve the constraints and an initial view of the data exchange data items.

Build / Test

During the Project's build and test phase, it became apparent that implementing an operational conflict avoidance process would be too difficult due to the following factors:

1. ESO services are dispatched near real-time and not necessarily scheduled, therefore making it difficult to share data or for a DSO to run operational conflict avoidance analyses; and
2. ESO assets were not located in the trial area and thus it was not appropriate to model the network to identify constraints.

Due to this complication and the infancy of ESO-DNO conflict avoidance in the industry, it was deemed impractical to implement an operational conflict avoidance process in the EFFS Trial. Moreover, due to the parallel work being undertaken by the Open Networks Project, anything established would have been superseded and very little learning derived.

Trials

It was deemed valuable to generate learning via the creation of a data exchange interface mechanism that could be used to inform the Open Networks Project. The Project designed a data exchange template that helped inform the Open Networks' Primacy work. The Project facilitated workshops to design the initial data interface layer that would be used between the DSO and ESO to exchange service data to support conflict avoidance. It was agreed that CSVs transferred via email or file transfers via an industry gateway could be used initially to start the process before a more

[7] Open Networks - Project 2021 Project Initiation Document - January 2021 | Version 1

thorough mechanism is established. One suggested future mechanism could be the use of the pre-existing mechanism Inter-Control Centre Communications Protocol (ICCP).

3.7. Stress Testing

Overview

At the beginning of the Project, it was envisaged that as more flexibility became available with changes in demand and an increase in electrification the network would undergo more stress and would experience more constraints. The Project aimed to stress test the end-to-end process to learn what effect this would have on future DSO systems.

Approach

The Project undertook a review of the Distribution Future Energy Scenarios (DFES) to plan the stress testing. Through the analysis, it was ascertained that running all the scenarios would not provide much learning. Largely because a stress test is about volume, and by running different permutations would merely show the worst case. The decision was taken to start by running the Steady Progression DFES scenario, notably a circa 10% increase in load, to test the process. To ensure the process got a real stress test the Project increased the number of sites from one BSP to the whole trial area. This resulted in:

- A single forecast run for the week;
- Powerflow analysis was generated for that week;
- This generated 25 constraints; and
- Simulation and creation of six bids for every service, a total of 150.

This was deemed a success with optimisation was performed in less than one second at choosing the cheapest services due to the solution being developed for large scale enterprise processing. A sample of the services optimised within this process can be seen in Figure 11.

Required Service				
Equipment ID	Service Type	Status	Service Start Date and Time	Service End Date and Time
330024	BAU / Scheduled	PROC_OPTIMISED	11/06/2035 09:00	11/06/2035 19:00

Available Service									
Equipment ID	FMZ ID	Platform	Flex Provider	Asset IDs	Service Type	Status	Service Start Date and Time	Service End Date and Time	Total Cost
330024	Plymouth_BSP	FlexiblePower	FlexProv35	3YN87	BAU / Scheduled	Dismissed	11/06/2035 09:00	11/06/2035 19:00	£742.42
330024	Plymouth_BSP	FlexiblePower	FlexProv32	4P2W9	BAU / Scheduled	Dismissed	11/06/2035 09:00	11/06/2035 19:00	£896.42
330024	Plymouth_BSP	FlexiblePower	FlexProv33	6DEZQ	BAU / Scheduled	Dismissed	11/06/2035 09:00	11/06/2035 19:00	£767.98
330024	Plymouth_BSP	FlexiblePower	FlexProv34	8E2JU	BAU / Scheduled	Dismissed	11/06/2035 09:00	11/06/2035 19:00	£830.17
330024	Plymouth_BSP	FlexiblePower	FlexProv31	X9ZVI	BAU / Scheduled	Dismissed	11/06/2035 09:00	11/06/2035 19:00	£755.80
330024	Plymouth_BSP	FlexiblePower	FlexProv36	YB2R9	BAU / Scheduled	**Procured**	11/06/2035 09:00	11/06/2035 19:00	**£623.67**

Figure 11: Service Example from Stress Testing

The Leading the Way scenario forecasts the heaviest increase in load and generation. An assumption was made that flexibility would be in abundance by the year 2035. Therefore, for every requirement / constraint, a corresponding six flexibility bids were created. Due to lack of liquidity, the market responses were simulated to ensure a true stress test could be executed. This enabled for testing of the optimisation, which was not available in the current market arrangements.

After successful completion of the Steady Progression, work went underway to stress test using the ‘Leading the Way DFES’ and this represented an average 35% increase in demand and circa 50% in generation sites.

This was modelled into the forecast and then run through powerflow analysis. Using this approach, the Project simulated six market bids for each constraint. In addition, we were able to test the other optimisation parameters. This was achieved by breaking the week into three parts:

1. Requirement parameters – This tested the optimisation, which selected each optimal bid based on dispatch lead time and the minimum and maximum bid duration.
2. Reliability parameters - This tested the optimisation selected the most optimal bids based on reliability parameters covering:

   a. Asset
   b. Provider
   c. Platform

3. Full scope – This tested a combination of all the above parameters combined to assess the optimisation and choose each optimum result.

During the stress testing, it became apparent through modelling the network for the 2030 scenarios that the existing network within the EFFS trial area may not have capacity for the future energy scenario. This demonstrated that the trial area may require some reinforcement to meet the networks future requirements and thus would not be met with stress as envisaged at the outset. Although stress testing provided the ability to sufficiently trial the optimisation process to simulate market liquidity to properly test different parameters.

4. Outcomes of the Project

4.1. The EFFS Method

The Project has delivered a documented process and method including developed tools, which could assist a DNO in operating the core activities required to deliver a DSO function. In particular, the EFFS Project has designed and delivered the component requirements to meet the ENA's Open Networks World model B[8] form of DSO. The EFFS system could be used to support system balancing by providing a means to identify, optimise and initiate the execution of flexibility services. It can select and enable flexibility services to operate across a network in a safe and secure manner.

The EFFS method could allow more automated access to a range of flexibility services, subject to their availability within a constrained area of the network, via directly interfacing with local flexibility platforms, flexibility pools or enabling access to other flexibility service providers such as suppliers with available flexibility or ready access to it. Providers of such services could compete with one another and the EFFS process would be capable of selecting the cheapest or optimum service based on set criteria. By facilitating the selection of flexibility services, EFFS could assist the development of the flexibility services market. In addition, The EFFS forecasting capability is robust and operating in conjunction with a suitable power flow analysis tool such as PSS®E, the EFFS method is capable of identifying the level of services required.

4.2. Forecasting

The outcomes of the forecasting method have shown that shorter-term forecast horizons can help a DSO better procure and manage flexibility in addition, aid decision making. The ability for DSOs to forecast at shorter time-horizons provides relies on the adequately specified tooling making use of input data including historic demand and generation data, and weather data. The EFFS output demonstrated what would be needed in a function specification to avoid limitations demonstrated during the projects forecasting implementation. The ability to have daily feeds of forecast data at different time-horizons can aid control room engineers to make decisions on the network and better inform the volume of flexibility to procure using the latest up to date information.

4.3. Constraint Analysis

The outcomes of the constraint analysis method demonstrated that it is possible to identify constraints on our network using an automated tool. This then allowed for forecast data to be used, in combination with other network properties, to see a view of the network in the future and appropriately select the flexibility services to mitigate the constraints. This can better inform flexibility procurement methodologies and be used to aid selection of service. The EFFS projects constraint analysis methods demonstrate that it is technically possible to carry out automated analysis using existing computing equipment, and therefore network operators are not limited to basic power flow tools when carrying out assessment on their network or making decisions on the procurement of flexibility.

4.4. Procurement and Selection of Services

The outcomes of the Project have shown that it's achievable to manage flexibility and select services under the ENA Open Networks World B model. Using forecast and power flow analysis data generated closer to real time can better enable DSOs to procure the right level of flexibility from parties. The method can enable DSOs to:

- Create flexibility requirements from constraints identified in power flow analysis rather than existing crude assumptions;
- Publish these to a multitude of different market participants and platforms;
- Optimise the lowest cost bid based on multiple selectable parameters, and;

[8] See Section 2.2 of Open Networks Future Worlds @ https://www.energynetworks.org/industry-hub/resource-library/open-networks-2018-ws3-14969-ena-futureworlds-aw06-int.pdf

- Validate that dispatching a new flexibility service does not create addition constraints elsewhere on the network

4.5. Platform Integration

The outcomes of the market platform integration proved that different market platforms can communicate with the DSO. The ability to have different market participants submitting bids to flexibility requests gives greater opportunity to obtain a commercially viable bid providing liquidity is available in the network area. Platform integration enabled interoperability with the flexibility market that as the market grows provide a better liquid pool for DSOs to procure services.

4.6. Technology Readiness Level

The EFFS Project began at Technology Readiness Level 6 as the technology and key software at that time had already been proved previously in a relevant environment. The design had not been completed as a finalised solution and would have required modification to make it operational. Through the testing and trial phases the Project achieved Level 7 as the technology was tested at or near full throughput and used simulations comparable to that expected during operations. Further developments and design work would be needed before any aspects of the EFFS system could be implemented but the outputs of the project have provided learning on how a BAU ready system would operate.

5. Performance Compared to the Original Project Aims, Objectives and Success Criteria

As described in the original Full Submission Proforma, the Project set out to address one of the key issues for DNOs in their transition to DSO. The issue relates to the changing electricity network, with higher levels of embedded generation, the emergence of storage and the uptake of low carbon technologies such as electric vehicles and heat pumps. These changes pose challenges for networks that were not designed to accommodate them. The Government's report 'Updating our Energy System: Smart Systems and Flexibility Plan'[9] suggests that the benefits of more flexible networks could be as much as £40bn by 2050, with part of that benefit coming from using markets in flexibility services to avoid traditional reinforcement where suitable. Avoiding the cost and disruption associated with installing assets that might only be required for short periods of time during a limited part of the year, alongside the potential to connect customers faster without reinforcement, is generally accepted to be desirable. While there had been several innovation projects that increased our understanding of flexibility services, such as Smarter Networks Services, FALCON and Low Carbon London, the various projects focused on individual niche areas of investigation and there were still some gaps in how to bring the various systems together to create a dedicated process. The aim of EFFS was therefore to provide DNOs with a system that can support new flexibility forecasting functions of a DSO.

EFFS has resolved this issue through delivering an innovative software system to exploit the benefits of flexibility, forecasting and procurement to resolve constraints on the network. In collaboration with industry partners, the Project confirmed the functionality required of DSOs, considered technical options for delivering that functionality and tested a technical implementation in practice.

Table 8 provides a list of the Project's objectives and the evidence to support completion.

Table 8 - : Objective Completion

No.	Objective	Status	Evidence
1	Enhance the output of the Energy Networks Association (ENA) Open Networks project, looking at the high-level functions a DSO must perform, provide a detailed specification of the new functions validated by stakeholders, and the inclusion of specifications for data exchange.	Complete	• Publication of a forecasting evaluation report and open-source XGBoost forecasting algorithm. • Production of requirements specification document outlining for DSO functionality, common protocols and approach to supporting these functionalities. • ENA and stakeholder collaboration strategy document. • Presentations at conferences and workshops to disseminate output.
2	Determine the optimum technical implementation to support those new functions.	Complete	• Production of system design documents outlining specific EFFS functionality and approach to delivering this functionality.
3	Create and test that technical implementation by implementing	Complete	• Build and delivery of the completed EFFS system, including technical design package release, deployment and configuration and system handover.

[9]See:https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633442/upgrading-our-energy-system-july-2017.pdf

	suitable software and integrating hardware as required.		
4	Use and test the technical implementation, which will involve modelling the impact of flexibility services.	Complete	• Test exit reports demonstrating completion of on-site testing to required standards; including integration, user acceptance, operational and performance testing. • Trials strategy document outlining trials approach and methodology, detailing approach to plant, system operations, supplier / aggregator and tandem operations trials. • Completion report demonstrating outcomes of trial phases alongside test scripts, exit reports etc. • Letters of support from external stakeholders and partners confirming completion of project trial phase and acceptance of results.

6. Required Modification to the Planned Approach during the Course of the Project

Table 9 below outlines the changes made to the approach during the course of the EFFS project:

Table 9 - Project Changes

Ref.	Date	Change	Reason for Change
1	15/09/2019	Follow-on work to the initial contracted work on forecasting to adjust the model to accommodate weather forecasts in addition to historical data, test engineering models for generation forecasting, test Durabill data as an alternative to SCADA data, determine automation options for forecast production, determine data cleansing options.	During the course of the planned forecasting work, data quality was assessed to be a prime reason for poor forecasts, engineering models were proposed for generation forecasting and the other
2	04/02/2020	To remove the facility to dispatch flexibility services from PowerOn via EFFS regardless of the platform used to procure them. This was intended to ensure a consistent process and no favouritism to one platform as may be expected by a Neutral Market Facilitator. Similarly, the ability to show the flexibility services available and known to EFFS via PowerOn has been removed from scope.	System simplification
3	04/02/2020	Remove the requirement to model the future behaviour of ANM systems as part of the process to assess flexibility requirements in the Capacity Engine.	The algorithms within the Cornwall ANM system are proprietary and there is no description of their operation that would allow for this to be accurately replicated within the network modelling tool PSS®E. While there is a “black box” simulator provided, this is not designed for automated integration within a time-sensitive process. The original purpose of including the impact of ANM systems was to prevent flexibility services being purchased that were not required. This anticipated BAU rollout where ANM systems are prevalent. The impact of over-purchasing flexibility services within the EFFS trial is negligible. Since the original EFFS proposal, there has been a shift in WPD’s expected management of ANM systems moving away from individually managed and maintained systems separate to PowerOn towards including this functionality within PowerOn.
4	20/07/2021	This change details nine solution design changes required to enable the EFFS Networkflow product to function as expected by WPD to meet the objectives of the EFFS project. The changes concern the use of sensitivity factors, the way in which system interfaces operate, and the format of data that is passed to/from Networkflow.	The AMT Sybex Networkflow design documentation was agreed by WPD on the understanding that some areas of the design required further consideration. When these areas were better understood by AMT, it felt that additional work was required to deliver core functionality, particularly around the way in which system interfaces ingest data.

7. Project Costs

Tables 10 and 11 below outline the EFFS spend and variance figures:

Table 10 – Spend during the EFFS project

Spend Area	Budget (£)	Actual Spend (£)	Variance (£)	Variance %
Labour	397,410	334,540	-62,870	-16%
Equipment	58,000	703	-57,297	-99%
Contractors	2,029,738	2,016,717	-13,021	-1%
IT	630,131	500,000	-130,131	-21%
IPR Costs	-	-	-	-
Travel & Expenses	39,741	37,171	-2,570	-6%
Payments to users & Contingency	81,960	4,000	-77,960	-95%
Decommissioning	-	-	-	-
Other	101,818	55,150	-46,668	-46%
TOTAL	3,338,798	2,948,281	-390,517	-12%

Table 11 - Variance Explanation

Spend Area	Variance Explanation
Labour	A variance in labour due to lesser than anticipated WPD project management time required by the Project.
Equipment	No physical equipment has been procured under the Project budget. The EFFS system was able to be run on existing WPD IT equipment.
Contractors	Lesser utilisation of forecasting and trial support sanctions.
IT	Underspend to date due to a lesser utilisation of forecasting and trial support sanctions.
IPR Costs	N/A
Travel & Expenses	Travel expenses less than anticipated due to COVID and a greater use of remote meetings.
Payments to users & Contingency	No contingency payments made. Change request 4, outlined within Section 6, had a cost that was charged to AMT-SYBEX's contractor sanction. Admin for the trial participation payed but payments to users were not made due to the need for constraint facilitation outlined within the work carried out section.
Decommissioning	N/A
Other	Audit cost within this area – no further costs that did not fit within the categories above incurred.

8. Updated Business Case

8.1. Updated Business Case

The original Project business case presented as part of the bid submission was predicated on the assumption that the Distribution Network Operators (DNOs) would need to transition to become DSOs. Details of this were specified in WPDs own DSO Transition Document[10] published in June 2017. This predicted that existing DNOs would need to take on some new responsibilities in addition to their existing obligations of developing and maintaining an efficient, co-ordinated, and economical system of electricity distribution, facilitating competition, and improving the resilience and security of the electricity system. Notably the need to facilitate neutral markets for more efficient whole system outcomes, driving competition and efficiency across all aspects of the system and the need to promote innovation, flexibility, and non-network solutions.

Since then, more work has been conducted by the government and industry. BEIS and Ofgem first published a Smart Systems and Flexibility plan in 2017 which has since been updated. The most recent publication released in July 2021 sets out a plan developed by the government and Ofgem in coordination with the energy sector, which sets out a vision, analysis, and suite of policies to drive a net zero energy system. Smart technologies and flexibility are essential to integrating low carbon power, heat, and transport onto the system.

The plan has 4 key areas of focus:

- support flexibility from consumers
- remove barriers to flexibility on the grid
- reform markets to reward flexibility
- monitor flexibility across the system

The need for flexibility will rapidly increase as variable renewable power replaces fossil fuel sources, and we electrify heat and transport. The plan sets out to drive smart systems and flexibility, based on the current energy market framework. The EFFS Project set out to explore what new processes a flexibility management system would require and then trial them.

Business Case

The Project business case was derived from two major components:

- The savings achieved from using a tested template solution incorporating a usable IT system; and
- The savings achieved from increasing the use of flexibility services by deferring conventional reinforcement for a period. This was recoded as benefit 1 in the updated Project bid submission.

There were in addition, further benefits identified at Project submission, which were not quantified and did not contribute to the financial benefit of the method.

Deferral of traditional reinforcement – Benefit 1

As part of the ENA's Open Network project, work undertaken in 2020 by Baringa Partners, delivered a tool for all DNOs to use in evaluating future investment decisions. The Common Evaluation Methodology (CEM) tool uses a methodology which enables all DNOs to follow a consistent process to identify which areas of a network could benefit from the use of flexibility. This is achieved by using various financial, forecasting, and technical network inputs to understand the costs involved across several different future outcomes. These can be compared to choose the optimal network investment.

[10] See https://www.westernpower.co.uk/smarter-networks/network-strategy/dso-strategy

Work undertaken using the CEM tool across the whole of the WPD footprint considered 96 schemes split between 41 in the East Midlands, 19 in the West Midlands, 9 in South Wales and 27 in the South-West. This Distribution Networks Options Assessment [11](DNOA) undertaken in March 2021, considered potential reinforcement schemes with a combined cost of over £274m. The total cost of flexibility procurement over the 5-year period considered in this DNOA was predicted to be £9.3m.

The Table 12 summarises the investment decisions concluded from this DNOA:

Table 12 - Investment Decision Summary

Investment Decision	East-Midlands	Midlands	South-Wales	South-West	Total
Flexibility	16	1	5	5	27
Reinforcement	12	8	2	12	34
Reinforce with Flexibility	8	6	1	8	23
Signposting	4	3	1	2	10
Remove	1	1	0	0	2
	41	19	9	27	96

Flexibility indicates a decision to procure flexibility or to maintain the flexibility contracts currently in place to defer reinforcement. Reinforce indicates a decision to pursue traditional network reinforcement immediately. Reinforce with flexibility is when reinforcement is set to begin immediately, but flexibility is still required to deal with the constraint in the interim. Signposting signals a decision to inform potential providers of future flexibility requirements, whilst the need requirement is monitored. Remove signals a decision to remove the scheme from consideration in future DNOAs. All schemes would be re-assessed in future (annual) DNOAs until there is no option value left to realise.

Original Financial Benefit

At the outset of this Project, as submitted in the Project bid, it was predicted that up to 10.8% of the total primary substations groups across GB could benefit from the use of flexibility for a period, as an alternative to conventional reinforcement. This would generate benefit savings of £114.4m over 10 years, rising to over £242m in the 30 years to 2050. Using the EFFS method to manage the use of flexibility, it could be possible for over £51m of conventional network reinforcement to be deferred for as much as 10 years within the WPD footprint area. This would generate a saving of £33.8 over those 10 years or £15.1m over just 5 years.

Updated Financial Benefit

The DNOA work detailed above has confirmed that the proportion of substations that could benefit from the use of flexibility was low. In-fact a total of 50 schemes would benefit from the use of flexibility over just the next 5 years. In addition, this work has identified that the average cost of each scheme deferral is slightly higher that originally estimated and stands at £2.85m per scheme as opposed to £2.55m originally estimated for use in the FSP bid submission. On this basis more than £77m of conventional reinforcement will be deferred by up to 5 years, suggesting that greater deferral savings are achievable than originally assumed. It should however be noted that such savings would be available using any comparable method of flexibility management to the EFFS method. In fact, such savings are already being realised using Flexible Power.

Using the additional information identified from the DNOA study and the other Project learning from the EFFS system requirements, savings of £43.3m (compared to £33.8m originally) would be achieved over 10 years or £20.4m could be realised in just 5 years (compared to £15.1m using the original assumptions) within the WPD foot-print area. This would translate up to a saving of £152.9m over 10 years if rolled out across the whole of GB to all the DNOs (compared to £114.4m originally).

[11] See https://www.westernpower.co.uk/distribution-network-options-assessment

8.2. Benefits

When the Project began four key benefits were identified. These were:

- Benefit 1 – Deferral or avoidance of traditional reinforcement
- Benefit 2 – Additional flexibility in fault restoration
- Benefit 3 – Reduced balancing costs via co-ordination with the ESO and
- Benefit 4 – Increased / faster renewables connections.

As seen from the previous section on the business case update, only the first benefit was used to help quantify the business case. This section provides an update on each of the remaining key benefits identified at the outset of the Project. As the Project has progressed and during the trials phase the aim has been to attempt to quantify these remaining benefits.

Benefit 1 – Deferral or avoidance of traditional reinforcement

The update for this has be given in the previous section on business case update.

Benefit 2 – Additional flexibility in fault restoration

At the time of project bid submission, the Engineering Recommendation P2/6, which details the design security standards for a distribution network, was under review. It was anticipated that at trials stage the Project would be able to contribute to the ENA working group reviewing this standard. However, this work was completed and a revised Engineering Recommendation, P2/7 now taking into account the use of flexibility assets was published in August 2019. This removed the need for the Project to contribute to this review.

Benefit 3 – Reduced balancing costs via co-ordination with ESO

One of the aims of the EFFS Project was to demonstrate conflict avoidance with the ESO. Notably, ensuring that the same flexibility plant was not selected for operation by both the ESO and the DNO for the same or overlapping period. During the trials phase the aim had been to share appropriate information on which flexibility services that the EFFS process had selected for service during the next period and to then ensure that this information was provided to the ESO to enable it to take appropriate action.

During the Project's build and test phase, it became apparent that implementing an operational conflict avoidance process would not be possible. Firstly, because ESO services are dispatched near real-time and not necessarily scheduled. Therefore making it difficult to both share data and enable a DSO to run operational conflict avoidance analyses. Secondly, as the Project entered the trials phase it became clear that the ESO had no plant within the trial area under service to them. Clearly this meant that there was no possibility of conflicted plant emerging. Further, it would not be appropriate to model the network to identify constraints.

Due to this complication and the infancy of ESO-DNO conflict avoidance work underway within the industry, it was deemed impractical to implement an operational conflict avoidance process in the EFFS Trial. Moreover, due to the parallel work being undertaken by the Open Networks Project, anything established would have been superseded and very little learning derived.

It was, however deemed valuable to generate learning via the creation of a data exchange interface mechanism that could be used to inform the Open Networks Project. The Project designed a data exchange template that helped inform the Open Networks' Primacy work. The Project facilitated workshops to design the initial data interface layer that would be used between the DSO and ESO to exchange service data to support conflict avoidance.

Clearly this sharing of information between DSO and ESO is an important process to ensure that each operator is not conflicted by the other. Also, this process holds more benefit for the DSO as overall, ESO service requirements can be provided at any point of connection to the national grid network whereas DSO service provision are much more local in nature and may only be sourced directly from a provided flexibility provided resource connected directly within the constrained zone. Although very valuable, for the reasons stated above, it has not been possible to quantify this benefit further.

Benefit 4 – Increased / faster connections

Historically, connection offers have been made based on conventional reinforcement, for example upgrading a substation by replacing or adding an additional transformer. With the introduction of the EFFS process method, new connection offers could include the use of flexibility management. As such, the delivery of many customer connections, including renewable generation or storage, would be able to connect sooner and more cheaply than would otherwise be the case.

To calculate the benefit of using flexibility management, the Project would study the historic list of connection offers made to determine which of these that had been prepared based upon conventional methods could have included the use of flexibility and as such would have enabled either a cheaper or faster connection offer to the customer. Unfortunately, when studied, the connection offer database did not hold sufficient information to enable the Project to determine if flexibility could have benefited the offer. The Project was therefore unable to quantify this benefit.

Further Benefit

During the trials phase the Project has demonstrated the EFFS capability to connect to different flexibility platforms. One purpose for doing this was to gather competing flexibility price offers and to demonstrate the optimisation capability within the EFFS system. This would demonstrate a further benefit that was not specifically identified at the Project start.

During the trials phase it was clear that there was a lack of liquidity in the provision of available flexibility across parts of the network and certainly at the trial locations. In addition, the CLEM project timing had not helped and therefore it was decided to use previously collected price offer data from the CLEM project rather than use on-the-day data which was not available.

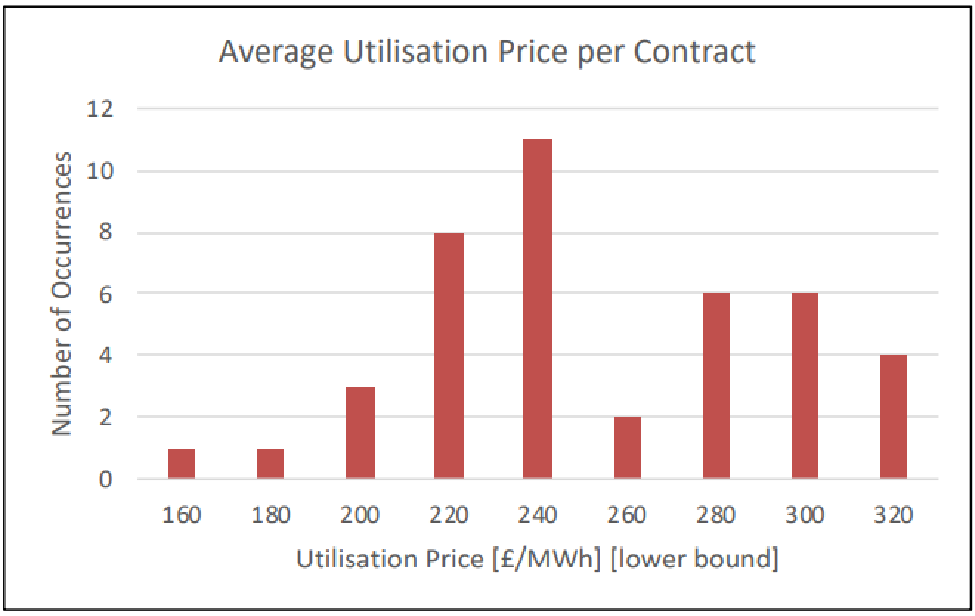


Figure 12: Average Utilisation Price Data

Figure 12 details the average utilisation price data collected by the CLEM project in the second half of their trials. This clearly shows that when there is sufficient liquidity in the market, utilisation prices can be competitive. Here a range of prices between £160 and £320 per MWh were obtained. The average price at £240/ MWh compares very favourably with the standard £300/MWh offering given as standard by the Dynamic service under FlexiblePower. However, such a level of liquidity is unlikely to be seen in many locations on the network and this lack of liquidity must be addressed to enable DSOs to have any real chance of benefiting from such prices.

9. Lessons Learnt for the Method

The following learning has been captured during the course of the EFFS project and is split into relevant areas of the project activity, as well as further more general points of learning.

9.1. Forecasting

Three forecasting methods were investigated as part of the forecasting evaluation phase; Auto-Regressive Integrated Moving Average (ARIMA) – A classic statistical modelling approach for building time-series forecasting models. Long Short-Term Memory Artificial Neural Networks – A specific type of deep learning neural network for learning patterns in time-series data. Extreme Gradient Boosting (XGBoost) – A machine-learning technique based on decision trees that has performed well in recent machine learning and forecasting competitions. The key outcomes from the forecasting delivered within this part of the EFFS Project include the following:

- Model performance: For the majority of test cases, Extreme Gradient Boosting outperformed the other methods tested (ARIMA and Long Short-Term Memory) in the projects early stages.
- Forecasting at different voltage levels and substation types: EFFS applied a series of techniques to Grid Supply Point (GSP), Bulk Supply Point (BSP), Primary, Load and Generation customers across multiple time horizons. The high-level results include:
    - Techniques based on historical data work best on short time horizons (hour ahead and day ahead). This result is seen across most of the voltage levels, including load and generation customers.
    - For the Primary and BSP cases with low penetration of wind and solar, relative to yearly demand, a feature set containing only temporal trends will provide predictions with acceptable levels of accuracy; for higher penetrations of renewables, predictions benefit from the addition of weather features to meet accuracy requirements.
    - For the GSP case, a GSP including connected solar and wind generation capacities comparable to that of its total demand were selected. The stochastic nature of the renewable generation made it more challenging to identify trends/patterns from historical data for the net real and reactive power flows at the GSP. By forecasting on an individual transformer basis and then aggregating the forecasts yielded better results. Although the results were only for a limited number of substations, this suggests DSOs may look build a large number of specific models to aggregate up to the GSP level to achieve the desired accuracy.

Following completion of the forecasting evaluation work by SGS in June 2019, a number of additional forecasting requirements not originally envisaged came to light. Had these requirements been identified at the outset when the forecasting requirements were specified, they could clearly have been included for in the tender. However, innovation projects such as EFFS by their very nature are exploring new requirements and therefore it should not be expected that a definitive set of requirements can be known at the start of any piece of work. Future innovation projects might look to mitigate this by including added budget or specifically hold back a small additional requirements budget to support the inclusion of additional requirements in a future tender if required.

Linked to the above point this additional forecasting work was explored. This followed on from the recommendations from the original report by SGS to explore the use of engineering models but also extends the use of weather data to use forecast values as well as historic data. However, this additional exploratory work did not significantly increase the accuracy of the forecasting or was inconclusive. Given this the decision was made that it did not offer value for money further exploring this or including these additional factors in the EFFS trials solution.

- As detailed in section 4.2, several forecasting learnings have been generated, namely:
    - Forecasting accuracy was impacted severely by government-imposed lockdowns because of the COVID-19 pandemic, as it meant that the historic load data used for forecasting was not typical;
    - Primary substations have a much higher degree of forecasting accuracy than other equipment types; and
    - Historic weather data appeared to have a limited impact on forecasts accuracy, but the impact of COVID-19 demonstrated the need for its inclusion with the low performance of forecasting during the EFFS trial period.

- Complexity of forecasting algorithm does not always lend itself to higher accuracy, as demonstrated by work carried out to compare forecasting outputs at the trial stage tools with clear inputs and more adaptability can achieve higher forecasting accuracy.

At the outset of the EFFS Project, forecasting was seen as a key component for providing a DSO system capability. However, this was before national system requirements had been discussed in any detail. Other DSO system readiness requirements were in the main silent on the requirement. The work undertaken by the EFFS Project in conjunction with the ENAs Open Network project, identified that forecasting was indeed a key requirement for DSO operation. This has been agreed by all GB DNOs and will form the basis for how demand side response systems determine how much flexibility to arm or despatch in operational timescales.

Early forecasting output in the trials revealed that using the Mean Absolute Percentage Error (MAPE) to measure forecasting accuracy was not always appropriate. When dealing with half hourly values of 0 or close to 0 (which is common for generation sites), this can cause either failure in the calculation or very large percentage errors, which make the errors seem disproportionately large. The Project therefore adopted a second accuracy metric, known as Mean Absolute Error (MAE), to put these very large MAPE errors caused by 0 values in the absolute context of a MW value.

Whilst not apparent with the currently levels of flexibility dispatched by DNOs, it was considered during the trial that forecasting will become less accurate without redacting flexibility dispatch from historic time series data that is used to train the forecasting model. This is because without redaction a feedback loop would be created where data containing post-dispatch network loading would suggest a lesser need for flexibility because constraints have already been actively mitigated.

9.2. Constraint Analysis Methods

Based on the learnings from the SGS forecasting evaluation report and the WPD experience of power flow analysis in PSS®E, it has been determined that forecasts at lower voltage levels were most appropriate to feed into the analysis carried out within the EFFS Tool during the trials. These inputs were then aggregated to higher voltage levels within the PSS®E package. Therefore, GSP and BSP forecasts were not required but rather forecasts are only required for Primary substation, 33kV connected customers and 132kV connected customers. Moreover, having forecasts at this level of granularity is especially beneficial because there was no need to alter the forecasts when the network configuration is non-standard, but rather the amended power flow was calculated in PSS®E.

The way in which non-convergent load flows are reported by a constraint analysis tool has an impact on its use for flexibility service selection. Occasional non-conversant studies were found in early runs of the trial period. Typically, the non-convergences were for one specific contingency and so the analysis for the rest of the time step would still be reliable. However, once the flexibility services have been identified, the same cases were run and so the non-convergent contingencies end up rejecting the services since the overload data is unreliable. The non-convergent load flow must therefore be accounted for prior to service selection being finalised.
Initially the EEFS tool aimed to resolve or improve constraints using flexibility services without any other constrained worsening. In reality this was not always possible. A more practical view would be to take into consideration some more factors when ascertain whether a constraint or contingency is critical. For example, some assets may be able to handle an overload more reliably than others and therefore preferential treatment would aim to resolve specific constraints as a priority.

If an automated system to implement planned outages is to be used by a constraint analysis tool, there must be consistency in the way it is presented. During the trial it was found that planned outages are recorded as free text data which assets and network locations difficult to match within the EFFS Tool's reference data. Changes to planned outage recording should be considered to resolve this,

9.3. Procurement and Selection of Services

At Project commencement, the EFFS team initially assumed that EFFS would have direct control of assets and would trigger services via flexibility platforms. However, an exploration of the concept of neutral market facilitation during WS1 led to the decision that EFFS will not have direct control of assets. Instead, there will be one single method to dispatch flexibility regardless of whether the asset is owned by a third-party or WPD, and this will be via whichever of the multiple flexibility platforms EFFS has procured the service from. This decision was made to ensure fair, equal and consistent interaction with flexibility platforms and to avoid any specific technology provider, or flexibility platform(s), being treated preferentially. EFFS was agnostic to these factors; all flexibility service providers were treated equally as long as they can fulfil the service requirements and provide value for money.

The optimisation in Networkflow was designed to error if an optimisation problem cannot be fully solved (i.e., there are not sufficient available services to completely fulfil the requirements). However, in markets that lack liquidity this condition is often not met, which causes the process to halt with an exception, and to accept the available services requires a manual workaround. If building an optimisation engine in the future the learning is to allow for partially solved problems.

The use of flexibility services as an alternative to conventional reinforcement has grown more rapidly than assumed since Project inception. However, the availability and necessary volume of flexibility services at each required point on the distribution network has not kept pace. This lack of liquidity must be addressed to enable DSOs to continue receiving the necessary benefit. Whilst work is underway to signpost requirements, for example using the DNOA, until the level of competition is improved availability and pricing certainty at required locations will remain an issue.

9.4. Platform Integration

Although the Smart Grid Architecture Model (SGAM) defined by the ENA Open Networks project give a high-level view of the types of data exchanges required to support the procurement and dispatch of flexibility services, this had not previously been defined to the level of agreeing data items. Through the WS1 workshops we have defined a proposed set of data items (based on the 4 service types defined by the ENA Open Networks) and drilled into the next level of detail which have been reviewed and agreed by various industry stakeholders as part of the DSO requirements document review cycle. This view evolved further during the technical design of the EFFS system, however it provided an additional level of detail and understanding to how the data exchange related to flexibility services will work in practice and therefore enhanced the learning of the SGAM.

Due to lack of common industry naming conventions for assets and network locations defining data exchanges within the EFFS systems has been a challenge requiring a great deal of data manipulation and mapping. This has been exacerbated by the data being dispersed within WPD across multiple systems. As we moved into the trial phase of the Project, we anticipate this issue became more pronounced as different organisations needed to be able to identify and communicate about assets, where they are on the network and how they relate to constraints and flexibility. The work of the ENA in developing the System Wide Resource Register is a step in the right direction, but we think a common industry data model, naming conventions and references (combined with increased openness of data) will reduce this issue and greatly support the growth of flexibility markets in the future.

Uniform interfaces to flexibility platforms have yet to be defined at an industry level. Without an agreed standard, EFFS defined its own default set of instructions for communicating with flexibility platforms with the assumption that any flexibility platform integrating to EFFS would use this standard (i.e. there will be no requirement to develop customised interfaces for EFFS to interface with platforms). The instructions and associated data items were derived from the service types defined by the ENA ON and the operational procurement, arming and dispatch processes defined by EFFS. In practice the flexibility platforms EFFS is interacting with are not yet interoperable in terms of service types and signals supported, however the data exchange developed within EFFS could be used across multiple platforms with slight tweaks to the associated business processes. This demonstrates that a uniform set of interfaces to flexibility platforms and interoperability is achievable.

One of the design assumptions going into the trial was that any data exchange with Cornwall Local Energy would be done manually via the web portal. However due to the volume of proposed services following the decision to use anonymised data from other locations (due to the lack of liquidity in the trial area) it became apparent this was not practical. Accordingly, a script to automate this data exchange was rapidly designed, developed, tested, and deployed. This massively reduced the manual effort required in the week to week running of the trials and reduced anomalies due to manual errors.

9.5. Conflict Avoidance

During the Project's build and test phase, it became apparent that implementing an operational conflict avoidance process would not be practical within the project due to the following factors:

1. ESO services are dispatched near real-time and not necessarily scheduled, therefore making it challenging to share data or for a DSO to run operational conflict avoidance analyses; and

2. ESO assets were not located in the trial area and thus it was not appropriate to model the network to identify constraints

Due to this complication and the infancy of ESO-DNO conflict avoidance in the industry, it was not possible to implement an operational conflict avoidance process in the EFFS Trial. Moreover, due to the parallel work being undertaken by the Open Networks Project, anything established would have been superseded and very little learning derived. However, it was deemed valuable to generate learning via the creation of a data exchange interface mechanism that could be used to inform the Open Networks Project.

9.6. Stress Testing

The initial stress testing run, representing an increase of around 10% in demand and generation, demonstrated that a future scenario could be run and optimised using the EFFS system. In this case constraints could be identified, services selected and then optimisation could take place. When carrying this out at a higher level of loading, representing 2035 conditions, the tool was once again able to take and use the forecast demand and generation data, but non-convergence caused by the network model being unfit for this use case meant that constraints could not be identified. It would be expected that the EFFS system can be used for assessing this level of forecast if the network model was able to converge during load flow studies, therefore representing the network reinforcement required.

Running of the EFFS tool under a 50% constraint threshold demonstrated the need for improved IT resource when generating large numbers of constraints and services. The tool was able to run successfully, but at this level the time take for simulations to take place was longer than would be acceptable for regular usage.

9.7. Trial Area Selection

Availability of data for assets to be forecast within the trial area need to be considered for any future area selection. The trial area selected in the EFFS trial contained generator sites, including the Multiple Fuel Type Generation site, which had no data to be used for input into the forecasting systems. This limited the output of forecasting in a way that meant the accuracy could not be assessed for this generation type.

9.8. Further Learning

The Project kicked off with a series of workshops designed to capture the full detailed requirements for DSO operation. However, it has not been possible to set out and agree a solution in the level of detail originally envisaged, since the EFFS Project has progressed ahead of the majority of compatriot work in this field. The result being that some areas are having to be revised by rerunning follow-up workshops when the necessary and external thinking has progressed to a sufficient level of detail. In retrospect, acknowledging that much of the work and necessary process is highly innovative and very new in nature, a two-part requirement gathering process might have been beneficial. This might have worked on an initial phase of developing a greater understanding for participants. Then running a second stage for capturing requirements. With participants having had more time to consolidate their understanding of how DSO might impact their business areas, the final workshops - which would have run later in the programme - would have been able to pick up a greater level of detail.

Due to the COVID-19 pandemic, Project resources were required to work remotely and in most cases from home. Initially, external Project resources could only be given direct access to WPD environments via Webex sessions. This proved a challenge as sessions could only be granted between 10:00 am and 4:30 pm and needed to be supervised by a WPD IT resource. Before trials commencement, however, WPD IT could offer external resources connection via CyberArk rather than Webex. This represented a more practical and enduring solution and should be considered in future projects that require external resources to have a direct connection to WPD environments.

The EFFS solution defined via the requirements and design phase of the Project was deemed appropriate for an enterprise BAU solution and to support the transition to DSO. However, during a review of the system architecture these were determined to be too onerous to implement in the context of an NIC trial. Therefore, during the system design and build phase, several design refinements were made to ensure the solution was appropriate, deliverable and pragmatic. For example, the EFFS system did not integrate in real time with WPD’s Network Management System (NMS) during the trials, as this was not essential for the demonstration of the solution and avoided extra cost, complexity and security requirements.

10. Lessons Learnt for Future Innovation Projects

Building on the learning documented within section 8.3, the following points of learning apply to work to be carried out within future innovation projects, and therefore relate to areas including project management, procurement, implementation and timescales.

- The duration and structure of the EFFS Project meant that BAU activity carried out alongside the Project within this area was often able to be more agile and have a faster response to changes within the industry. For this reason, non-infrastructure projects lend themselves to a shorter sprint delivery timescales, allowing for outputs to be worked on and transitioned to the business over the course of the Project.

- During the later stages of the Project, WPD Innovation resource working on the Project increased to ensure a project manager and technical lead were engaged. This approach improved efficiency on the Project significantly. This improvement came as review times were able to be reduced and outputs of the Project were overseen by both parties.

- One challenge in the Project phases included designing a solution across multiple software solutions, provided by different vendors. During the requirements and design phase, it was difficult to ensure that the solution hung together across different systems and that the integration points were aligned and agreed upon. To resolve this the Project appointed a solution architect to oversee the solution across all systems, and be responsible for agreement of integration points and protocols and rationalising the solution to ensure consistency / remove duplication. This benefitted the Project greatly and enabled the delivery of a functional pragmatic solution with which to carry out the EFFS Trials.

- When the EFFS Project was originally planned and mobilised a waterfall methodology was agreed in terms of project management, design and delivery. Namely that a set of requirements would be defined, this would then cascade into a design, the build, and finally the trials. However, in practice this approach did not cater for the innovative nature of the Project, specifically, that thinking, and requirements would be fluid due to external industry developments and internal learnings within the Project. The waterfall nature of the Project meant it was difficult to return to the early phases to amend requirements, design, and approach. The barriers within this approach were governance, deliverable, and phase structure. Also, re-visiting earlier phases often led to rework. To avoid this if running the Project again we would consider the use of an agile approach.

- Originally it was expected that the key Project role of Forecasting Partner might be attractive to many academic institutions as well as commercial service providers - such as the party selected Smarter Grid Solutions - with expertise in this field. However, when the tender was issued in November 2018, in order to keep to Project timescale and the closeness to the Christmas break, only four weeks was available for interested parties to prepare and respond to the tender. Of the tenders received only one involved an academic party and this was received as a joint bid in conjunction with a commercial organisation. A wider and increased field of bidders might have been achieved if:
    - a longer prequalification process had been possible;
    - more time had been allowed for parties to prepare their bids; and
    - the process had not been as close as it was to the end of the year.

11. Project Replication

11.1. Forecasting

Overview

The XGBoost forecasting algorithm was developed using an open-source toolchain. This is publicly available with instructions and a guide on how to install the toolchain and an explanation of the code. This can be downloaded from the WPD EFFS Project Website www.westernpower.co.uk/projects/effs and the Forecasting Evaluation Report contains all this information.

Business-as-usual cost

There are no upfront BAU costs for the replication of the Method as the forecasting tools have already been developed and tested. There is no direct cost associated with the toolchain, however, to replicate this for an entire network would be a significant amount of resource to run in normal running arrangements. Therefore, it would be significantly costly to run manually at an entire network level. The labour cost to run would depend on the frequency of forecasting and the number of horizons being forecasted.

11.2. Constraint Analysis Methods

Overview

Constraint analysis was carried out during EFFS using the EFFS tool developed by PSC. This tool makes utilises python and its interface with PSS®E, with a graphic user interface in place to ensure ease of use. As this tool was developed as part of the Project under the default Intellectual Property Rights (IPR) requirements, this is available to all other parties.

Business-as-usual cost

No cost as default IPR position applied. Please contact wpdinnovation@westernpower.co.uk for access to this tooling.

11.3. Procurement and Selection of Services

Overview

The procurement process can be replicated through using the system design documents either through a manual method or developing a system. The system design documents published on the EFFS Project website would be required to replicate this process:

- System Design: Service Management[12]
- System Design: Optimisation[13]
- System Design: Scheduling[14]

Contained within each of these documents is the information and detail required to replicate the flexibility procurement process and selection process.

Business-as-usual cost

The cost to replicate this process could be achieved by a DSO using the system design documents and replicate the process using their resources to develop a solution, the costings for this would not be practical to estimate financially given the number of variables involved in designing, developing and implementing software.

[12] See System Design: Service Management @ https://www.westernpower.co.uk/downloads-view-reciteme/64084
[13] See System Design: Optimisation @ https://www.westernpower.co.uk/downloads-view-reciteme/64081
[14] See System Design: Scheduling @ https://www.westernpower.co.uk/downloads-view-reciteme/64078

11.4. Platform Integration

Overview

The outcome of this Project demonstrated the ability of a DSO to facilitate market interactions using data exchange between parties. The Project created bespoke interfaces to communicate in CSV, but another party could create the same interface by following the System Design Document Market Interface[15]

Business-as-usual cost

The cost to replicate this process could be achieved in one of two ways, a DSO could use the system design documents and replicate the process using their resources to develop a solution. The costings for this would not be practical to estimate financially given the number of variables involved in designing, developing and implementing software. Alternatively, as the market interface was developed using CSV file formats, this could be replicated manually but would not be scalable for dealing with large volumes.

[15] See System Design Doc Market Interface @ https://www.westernpower.co.uk/downloads-view-reciteme/64096

12. Planned Implementation

12.1. Whether and how we plan to modify our network based on learning from the Project

No network modifications will take place as the project developed a software system.

12.2. What needs to happen, including any necessary further work, before the Method(s) can be implemented

Due to the nascent nature of the flexibility market, we do not believe that there is a current requirement for an EFFS-like solution.
As the market develops and becomes liquid over the coming 5 years, we are concerned and aware that a greater need will arise for an EFFS type solution, and we will assess relevant technologies that could evolve and deliver the same or better outputs and benefits more effectively for customers.
We intend to keep an active watching brief on the global development of AI/ML type solutions that could help deliver these outcomes in the future.

Further work would be needed on the forecasting system developed within EFFS to further increase accuracy based on learning from the duration of the project. The learning from the project has demonstrated what was successful and unsuccessful with the EFFS forecasting method and this will influence the development of our BAU forecasting method.

12.3. The likelihood that the Method(s) will be deployed on a large scale in future

Further automation of flexibility identification and dispatch is an inevitability but requirements from our business have changed throughout the EFFS Project lifecycle and are expected to be under constant review given the nature of flexibility, its nascent nature and the changing appetite for its provision by FSPs. For this reason, the full EFFS system will not be deployed within our Business as Usual activities, but elements and learning will be deployed to support these practices.

Moreover a vision of what we believe is reasonable as an approach is given in 11.2

12.4. The requirements required by Network Licensees and actions required by Non-Network Licensee parties

No actions are required at this stage.

12.5. Recommendations on how the outcome of the Project could be exploited further

Detailed learnings are going to be taken forward by our DSO team to help inform the approach WPD takes when its requirements for an EFFS solution are more robust and detailed. We would be available to provide our recommendations and advice on what a forecasting system needs to look like, and would be happy to discuss the learning from the project with any interested parties.

13. Learning Dissemination

Learning dissemination is critical during an innovation project to share the knowledge accumulated. Dissemination was conducted using a variety of methods. Table 13 below outlines the various ways information from the Project was disseminated. Note: It was intended that the end of Project dissemination would be carried out via in person workshops or conferences. However, due to the impact of the COVID-19 pandemic on both travel and social interaction, plans were changed. The planned workshops were replaced by webinars, which allowed people to attend the dissemination events easily while adhering to the restrictions in place to limit the spread of COVID-19. This alteration did not reduce the effectiveness of Project knowledge sharing.

Key dissemination activities are listed in the Table 13 below:

Table 13 - EFFS Dissemination Activities

Activity	Date	Description
Press release	October 2018	A press release for the EFFS Project was released by WPD and AMT-SYBEX.
Website	October 2018	EFFS Project information was uploaded to the WPD website.
Presentation	October 2018	The EFFS Project was represented by the WPD and AMT-SYBEX project team at the Low Carbon Networks & Innovation event in Telford.
Video	October 2018	EFFS introductory slide pack and voiceover were uploaded to YouTube and the EFFS Project webpage on the WPD website.
Presentation	December 2018	EFFS was presented as part of the T.E.F. Group at ENTSO-E National Grid event.
Webinar	March 2019	EFFS provided the T.E.F. Group with a Forecasting Evaluation Q&A session to provide them an update on algorithm development, to assist with understanding and support handover of the open-source tool.
Calls	October 2018 – June 2019	Collaboration between SGS and National Grid to share best practices in terms of forecasting approaches and methodologies.
Industry review	April 2019	EFFS issued its DSO Requirements Specification to T.E.F. and relevant industry parties for review. EFFS addressed all review comments and achieved the relevant stakeholders' support.
Webinar	May 2019	EFFS provided T.E.F. and relevant industry parties with a webinar / Q&A session on the DSO Requirements Specification.
Presentation	May 2019	EFFS Project overview and early learnings from forecasting evaluation disseminated at AMT-SYBEX's Forecasting the Future event.
Webinar	June 2019	EFFS provided the industry with a webinar to disseminate the forecasting evaluation work.

Industry review	August 2019	EFFS DSO Requirements Specification and Forecasting Evaluation Report shared with ENA Open Networks Workstream 5 – Communications.
Leaflet	October 2019	Double-sided leaflets were designed and produced for the LCNI 2019 event to provide visitors of the WPD stand an overview of EFFS.
Presentation	October 2019	The EFFS Project was represented by the WPD and AMT-SYBEX project team at the Low Carbon Networks & Innovation event in Glasgow.
Presentation	November 2019	The EFFS Project was represented by the WPD and AMT-SYBEX project team at the WPD Balancing Act 2019 Event in London.
Meeting	April 2021	EFFS provided OFGEM with a “show and tell” event on the Project.
Presentation	October 2021	EFFS presented at the Energy Networks Innovation Conference (ENIC) 2021.
-	Duration of the Project	Engagement with ENA ON relevant workstreams.
-	Duration of the Project	T.E.F. project delivery board meetings.

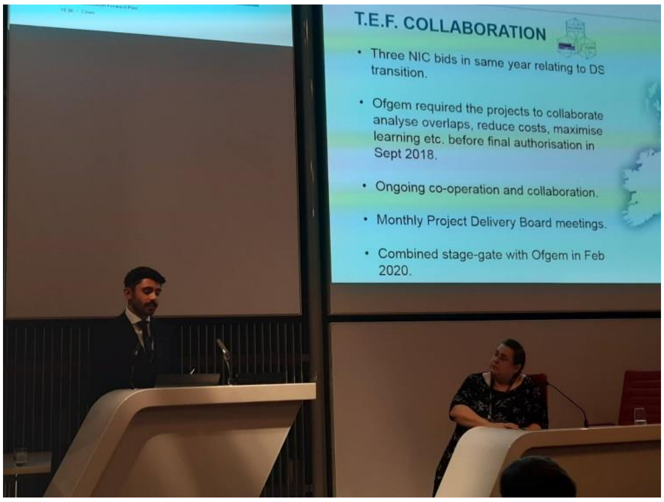


Figure 13: EFFS presented at WPD Balancing Act 2019 Event

Cost-saving for T.E.F.

EFFS led the Forecasting Requirement process with FUSION and TRANSITION supporting and assimilating outputs. The joint development in the area of forecasting throughout the first 18 months of the Projects resulted in TRANSITION realising a previously unidentified £98.5k saving; the full amount of which will be returned at the end of the Project. FUSION assessed internally and applied the EFFS algorithms to an existing tool; WaNDA, while TRANSITION commissioned independent EFFS forecasting due diligence, outlining the paths which meet TRANSITION and LEO needs. The forecasting efficiency advances the newly identified T.E.F. additional collaboration savings total to £148.9k. Such improvements in value for customer’s money were only possible through collective development and pivotal alignment work.

14. Key Project Learning Documents

This section outlines the key documents used to capture the learning and progress throughout the EFFS project. These can be found on the EFFS page on the WPD website at westernpower.co.uk/projects/effs

14.1. Project progress reports

Progress report 1 – October 2018 to March 2019
Progress report 2 – April 2019 to September 2019
Progress report 3 – October 2019 to March 2020
Progress report 4 – April 2020 to September 2020
Progress report 5 – October 2020 to March 2021

14.2. Presentations / Events

- Press release for the EFFS Project was released by WPD and AMT-SYBEX in October 2018;
- Low Carbon Networks & Innovation event in October 2018;
- ENTSO-E National Grid T.E.F. Event in December 2018;
- Q&A webinar session with T.E.F. in March 2019;
- AMT-SYBEX's Forecasting the Future event in May 2019;
- Dissemination webinar to industry stakeholders in June 2019;
- Low Carbon Networks Innovation event in Glasgow in October 2019;
- WPD Balancing Act event in November 2019;
- Energy Networks Innovation Conference virtual conference in December 2020.

14.3. Project Deliverables

PD-1 – Mobilisation Exit Report
PD-2 – Output from the forecasting and conflict avoidance
PD-3 – Development of requirements specification for DSO functionality
PD-4 – Development of EFFS Design Specification document
PD-5 – Implementation and System Delivery
PD-6 – Completion of on-site system testing
PD-7 – Trials design and preparation
PD-8 – Trials – execution and knowledge capture
PD-9 – Gateway reviews
PD-10 – Knowledge Dissemination Co-ordinate with any other DSO related NIC projects and comply with knowledge transfer requirements of the Governance Document.

14.4. Additional Reports and Data

TEF Stage Gate Report, which was approved by Ofgem in March 2020.

15. Data Access Details

Data sets from the EFFS trial are available on the WPD website. This includes data from each weekly run of the EFFS system where demand and generation has been forecast within the south west license area.

16. Foreground IPR

The EFFS Project conformed to the standard NIC IPR requirements, and therefore all IP developed during the course of the Project is to be shared. The IP generated during the Project includes:

- XGBoost Forecasting Algorithms – shared by means of the reports outlining its design and methodology as well as by the sharing of the Jupyter notebooks. This is available on the WPD website: westernpower.co.uk/projects/effs
- EFFS Tool – a python tool developed by PSC, available by request at wpdinnovation@westernpower.co.uk
- Reporting and Documentation - the documents developed during the course of the EFFS project, outlined within section 13, are available on the WPD website: westernpower.co.uk/projects/effs

17. Material Change Information

There were no material changes during the EFFS Project’s lifecycle.

18. Contact Details

For access to the Project's learning or if you have any questions relating to this document, please use the following points of contact:

Innovation Team:

Western Power Distribution,
Pegasus Business Park,
Herald Way,
Castle Donington,
Derbyshire
DE74 2TU

Email: wpdinnovation@westernpower.co.uk

Appendix 1 – Peer Review Letter of Support

6th December 2021

Ryan Huxtable
Western Power Distribution
Avonbank
Bristol
BS2 0TB

Dear Ryan,

Re: Peer Review of the EFFS Close Down Report

Electricity North West confirms that Western Power Distribution provided a draft copy of the EFFS project close down report for review during the course of its closedown preparations. This report was then robustly reviewed by **Electricity North West** and comments were provided to Western Power Distribution to demonstrate where changes should be made. Following this, updates were made to address all comments prior to any publication of the close down report.

Electricity North West confirms that the report is clear and understandable and provides sufficient information to enable a Network Licensee, not closely involved in the Project, to effectively consider whether and how to implement the Project's learning in to its business as usual activities.

Yours sincerely,

Ben Ingham

Digitally signed by Ben Ingham
CN=Ben Ingham
C=GB - UNITED KINGDOM
O=ENWL
E=ben.ingham@enwl.co.uk

Ben Ingham
Innovation Technical Manager
Electricity North West

Glossary

Abbreviation	Term
ANM	Active Network Management
ARIMA	Autoregressive Moving Average and Autoregressive Integrative Moving Average (Statistical Time Series Algorithm)
CLEM	Cornwall Local Energy Market (Platform)
CSV	Comma Separated Values
DFES	Distribution Future Energy Scenarios
DNO	Distribution Network Operator
DSO	Distribution System Operator
EFFS	Electricity Flexibility and Forecasting system
ENA	Energy Networks Association
ESO	Electricity System Operator
GUI	Graphical User Interface
HH	Half Hourly
IIS	Interruptions Incentive Scheme
IPR	Intellectual Property Rights
LSTM	Long Short-Term Memory (Deep Learning Algorithm)
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MW	Megawatts
MVAr	Megavolt ampere of reactive power
NIC	Network Innovation Competition
PSC	Power System Consulting
SGS	Smart Grid Solutions
SHAP	SHapley Additive exPlanations
STOR	Short Term Operating Reserve
SIT	System Integration Testing
TS	Time Series
TSO	Transmission System Operator

UAT	User Acceptance Testing
WPD	Western Power Distribution
XGBoost	Regularizing Gradient Boosting (Machine Learning Algorithm)

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