A WHOLE SYSTEM PERSPECTIVE FOR ENERGY SYSTEMS

Ralph HUDSON
Energy Systems Catapult – UK
ralph.hudson@es.catapult.org.uk

Phil LAWTON
Energy Systems Catapult – UK
phil.lawton@es.catapult.org.uk

ABSTRACT

The Future Power System Architecture (FPSA) Project was commissioned by the UK government to investigate the technical challenges the power system is anticipated to face by 2030, assuming an outcome identified by National Grid's "Gone Green" energy scenario [1]. The analysis concentrated on the power system technical architecture and adopted core systems engineering principles to give all parties a single point of reference against which different strategies could be compared.

This is one of three Working CIRED 2017 Papers relating to the FPSA project. The others are Working Paper 0067: International review of how power sector developments are responding to changing system characteristics and Working Paper 0234: What does a distribution system operator need to know about the findings of the FPSA project.

INTRODUCTION

The task identified by the UK's Department of Energy and Climate Change (DECC) (whose portfolio in now part of the Department for Business, Energy and Industrial Strategy), was based on the recognition that transformative change within the energy sector would unavoidably involve major challenges that have not yet been addressed through industrial or regulatory structures. The Project was asked to articulate the specific functions that need to be undertaken to address these challenges.

The well placed emphasis on 'functions' rather than 'requirements' made it clear that the conclusions drawn had to be actionable in the real world. The nature of these functions varies across four timescales: investment planning, operational decision making, real time operations, and timescales driven by market and settlement processes.

Functions were defined as hardware or software based capabilities, services, tasks, roles or any other action that can be assigned to a system or organisation. They can be implemented by an enterprise, organisation or system, depending on whether they represent a service, role or software functionality.

MAIN CHALLENGES

In considering how the energy sector can respond to the many individual challenges its members face, the Project had to identify the main aspects of the power system that the functions will need to support and the functions that are most important for transformational change. The analysis also had to consider how and when the functions could be implemented.

PROJECT BOUNDARY

The project took a whole system approach to the power network, covering the entire GB interconnected power system and all connected apparatus: generation, demand, storage and interconnectors to other systems. Issues of governance were excluded, but interests of stakeholders (customers, commercial organisations and the government) were considered.

Vectors other than electricity were excluded, raising questions from some observers, but it soon became apparent that the ability to electrify services and offer a more adaptable power system is a fundamental priority that needs to be understood without building in immediately the variables and trade-offs that a multi-vector analysis would introduce. The focus was kept on the functions that need to be enhanced or introduced, not on specific outcomes for the energy sector.

APPLIED METHOD

The approach taken had to be based on clear principles and a methodology that allowed all parties to agree from the start the questions to be addressed. A short but carefully tailored glossary helped participants apply common terminology to issues that span multiple perspectives across and beyond the energy sector.

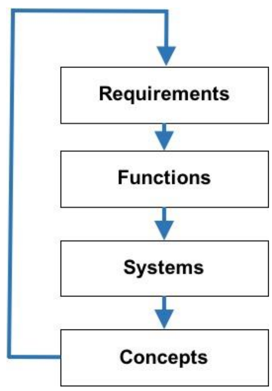

Figure 1 – Iterative Basis for the Analysis

The foundation of this work was the highly iterative process at Figure 1. Given the lack of any formal requirements set that could be applied across the energy sector, the functions themselves were made the primary focus of the analysis.

The 'Requirements' were treated as any statement of stakeholder need and the previously defined issues and challenges facing the power system.

'Functions' identified what people, organisations and systems have to do and the levels of performance that have to be achieved.

'Systems' were defined as the means of implementing the functions, whether infrastructure or organisations. The interfaces between systems represent the interactions and relationships by which they operate.

'Concepts', as discussed below, were defined as configurations of systems by which the effectiveness of alternative strategies could be explored.

Concepts

The building of 'concepts', Figure 2, was the foundation of the analysis. They were modelled by mapping functions onto systems in configurations that represented a particular strategy of interest, whether for specific challenges or for the power sector as a whole.

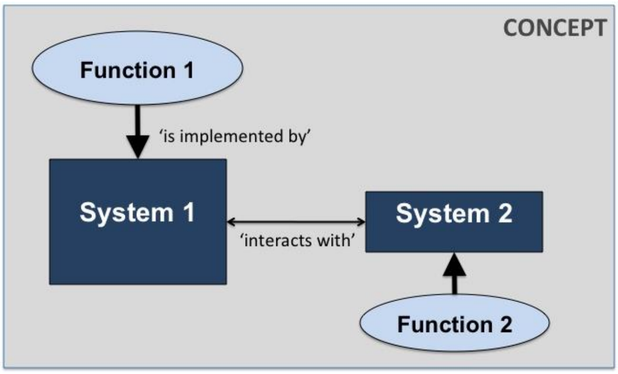

Figure 2 - Mapping functions onto systems to build concepts

The starting point was a diagram that displayed the entire electrical energy system on one page as a framework of interconnected systems. This template was then marked up to show the power flows, information flows, control signals and commercial commitments envisaged to create a system of systems. For clarity, the arrows were colour coded:

Black: Power Flow
Red: Direct Control
Green: Monitoring (e.g. of power network)
Blue: Data Flow
Grey: Contractual Relationship

Figure 3 (Page 4) is an example marked up to show how home automation might be achieved using the internet to pass control signals.

These diagrams proved to be invaluable for:

Developing new concepts: Marking up the diagrams provided a disciplined and systematic check of the logic behind the concept and tested both the completeness and feasibility of functions embedded.

Communicating and debating concepts: The diagrams are both concise and unambiguous which minimised misunderstandings when the group were discussing the different concepts.

Recording the concepts: It was possible for a single A4 sheet or Power Point slide to record all the necessary information about a proposed approach in a visually accessible form.

Members of the group were encouraged to generate lots of exploratory concepts addressing the issues that were concerning them. Early examples included risks to the distribution network caused by the widespread adoption of new loads such as electric vehicles and heat pumps or distributed generation such as solar photo-voltaic. This approach encouraged innovation and ensured that all members of the group could investigate the issues that most concerned them and have their proposed solutions recorded.

The diagrams were used throughout the process of concept development described below. The exploratory concepts that were mutually compatible were grouped together and were the basis for developing a more holistic view. As the project moved from exploratory concepts to a broader view that incorporated strategies for the entire power system, it was necessary to produce separate diagrams to cover the four different time scales noted at the introduction.

CONCEPT DEVELOPMENT

As the early concepts, such as the one at Figure 3, were debated, additional analysis was applied.

Key System Aspects

Each was assessed for its contribution to 8 key aspects of the system, under 3 headings.

Customer Related: (1) How customer appetite for the strategy could be encouraged. (2) How Demand Side Management (DSM) could be most effective.

Network Related: (3) How network capacity could best be used. (4) How additional capacity should be provided. (5) and (6) How both frequency and voltage should be

managed.
Production Related: (7) How the dispatch process should operate. (8) How the generation portfolio should be developed.

Functional Matrix

With expert help from specialist consultants, the functions emerging from the concept development were identified and compared to the related functionality already in existence. The specific need for each function, the impact of its introduction or modification and the evidence to justify its inclusion were collated.

Although specific solutions were not needed, credible options for the implementation of each function were identified, supported by an assessment of the likely impact, timescales and sequence of events.

CASE STUDY: AUTOMATED DEMAND SIDE RESPONSE (DSR)

The following is an example of the many issues that were explored using this methodology.

The existing distribution networks were designed to meet the highest anticipated load, so that there was no need or provision for controlling demands to avoid overloading the network. As we start to electrify heat and transport, large additional loads will be placed on the distribution network. In the absence of any incentives, customers will tend to operate their Heat Pump (HP) in a similar way to their previous gas boiler and put their Electric Vehicle (EV) on to charge when they return home in an evening. This approach will both overload the local distribution network and greatly increase national peak demand. (The two largest costs of uprating the system are the local network and the generation to allow it to be used.) If demand side response can be used to move non-time critical demand, such as charging an electric vehicle, away from the peak, this will greatly reduce the costs of electrifying heat and transport.

Workshop Conclusions

The first set of workshops led to the following conclusions.

Only the network operators have visibility of the network loading and their duty to ensure that it is operated safely requires contractual certainty that DSR will be delivered when requested. This implies a new contract in addition to the existing one between the customer and their supplier or community energy manager/aggregator.

The large number of potential constraints and the desire to minimise customer impact both point to the need for automation.

A vital aspect of customer acceptance is limiting the impact on their lifestyle. Scheduling the charging of their EV may be acceptable, but the temperature of their home must be managed within acceptable limits.

The integrity of the communication channel used will be critical to security of supply.

Some form of home energy management system will be required to implement the DSR instruction.

While automated DSR presents implementation challenges, the alternative of national upgrading of distribution networks and attempting to meet an increased national peak demand using low carbon generation will be very expensive.

DSR impacts all the Key System Aspects. In particular, it is central to customer appetite for engagement, demand side management and radial network capacity.

A second set of workshops discussed DSR in the context of whole system strategies and compared DSO intervention by contract with suitable contract arrangements negotiated via an aggregator. These discussions addressed how the arrangements could be made acceptable to the customer, both by offering incentives to enter into a suitable contract and also by use of an aggregator or other party to minimise the impact upon the customers’ life styles.

Not surprisingly, when the automation of DSR was discussed in a wider context of possible strategies for GB, it featured in every approach other than ‘Business as Usual’. (See Core Concepts, below).

Entries to the Functional Matrix

The importance of automated DSR comes through in the functions matrix in that it is identified as being the main driver for 12 out of the 35 functions, notably the following:

Network monitoring. To monitor in real time both the load flow and the available network capacity.
Forecasting of network conditions, generation and DSR availability. To enable constraints to be anticipated.
Assessment of the trigger events and associated locations/volumes of DSR to be despatched. To identify the actions that will be required for each contingency. Given the large number of potential constraints, this process will generally need to be automated.
Ability to implement DSR. A mechanism to implement the required demand side actions when required. Again, this will generally need to be automated.
Monitoring to ensure the DSR has delivered the desired outcome. To keep the system stable across all vectors and help all parties meet their obligations.
Recovery from major events. To ensure stable load

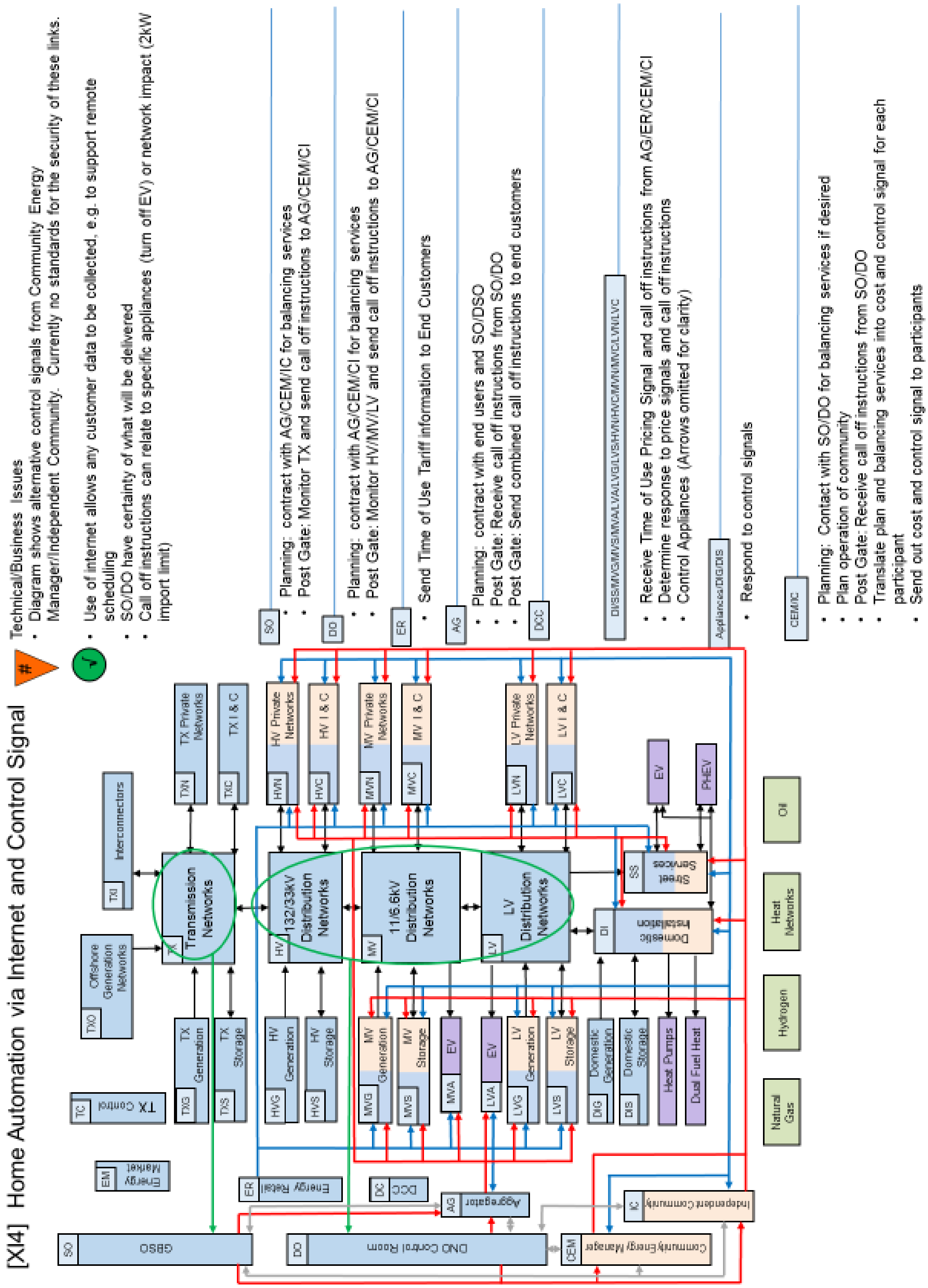

Figure 3 – Case study for Automated Demand Side Response (DSR)

management in real time when restoring areas affected by blackouts. With increased use of heat pumps and electric vehicles, these loads are likely to come on with zero diversity when power is restored after a lengthy outage.

In addition to these technical functions, there will be a need for:
Communication channels. To link the various functions.
Contractual Rights. To protect customers and incentivise their participation.

The full content of the Functional Matrix can be found at [2].

In many ways, automated DSR will mimic the way that the transmission system is managed today. The main difference is that the much smaller number of circuits and nodes on the transmission system allows for greater manual involvement by control staff, both in the control centre for monitoring and at power stations to implement the required actions. Transmission constraints are generally resolved by constraining generation rather than influencing demand. In contrast, DSR inherently involves the provision of incentives, controls, restrictions and working agreements that limit demand directly.

Case Study Conclusions

Automated DSR will allow more energy to be delivered by the distribution network without expensive uprating work. It will also "flatten" the daily load profile, allowing generation to operate with a higher load factor and limiting the need to build more generating capacity.

The impact on customers is a key factor. People need to trust the services they receive, even if they often take little interest in the operations behind them. The development of home energy management systems which give people control over the way they use and pay for energy is essential if the overall system is to deliver the flexibility and efficiency by which the country's emissions can be reduced.

CORE CONCEPTS

As issues such as DSR were debated, four core concepts emerged from this work as representative ways by which the power sector could move forward:

Power sector adaptation: The power sector maintains Business As Usual, an evolutionary approach accommodating incremental developments and remaining largely reactive to new demands and opportunities. There are no expectations of major changes in customer behaviour.

Power sector leadership: The power sector provides leadership, engaging with more active consumers. There is a development of existing statutory and licence obligations with Distribution Network Operators (DNOs) undertaking Distribution System Operator (DSO) roles. All System Operators coordinate together for an integrated approach to balancing and constraint management.

Customer empowerment: The power sector becomes the facilitator, empowering commercial parties and consumers. Individual customers and commercial parties drive events with customers adopting new business models, both singly and via virtual networks. New sector arrangements facilitate the entry of third parties, new services and grid edge technologies.

Community empowerment: The power sector expands its facilitator role, empowering communities and smart cities. Driven by local community interests and strong growth in "smart city" infrastructure, communities, both geographic and virtual, have the flexibility to follow complex agendas. This aligns with the "Internet of Things" with greater Peer to Peer engagement, including local markets and services.

CONCLUSIONS

The whole system perspective, as set up for FPSA and developed in this paper, helped collate evidence that 35 functions are fundamental to the evolution of GB's power system. These are being addressed by in the next phase of the work: FPSA2.

The authors hope that the framework developed in this paper will remain a foundation on which the impact of different decisions for the electrical power system can be assessed without excessive effort.

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