DEVELOPMENT OF METHODS AND MODELS FOR A STUDY INTO UK DISTRIBUTION SYSTEMS OF 2030

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ABSTRACT

This paper summarises a detailed, large-scale technical study into distribution systems for 2030, which is being undertaken on behalf of all the electricity network companies in Great Britain (GB). The paper provides background information and the motivations behind the project, as well as describing the study methodology and detailing important elements of the approach. These elements include future energy scenarios, smart network solutions, key issues for the industry, use cases to address the key issues and nodal network models, which will be made publicly available.

INTRODUCTION

In GB, the Smart Grid Forum (SGF) [1] has been exploring the challenges of transitioning Britain to a secure, safe, low carbon, affordable energy system. Which technologies will feature in future distribution systems has been a key concern, and previous work by the SGF's Work Stream 3 [2] has shown which innovative technologies are most financially attractive and their predicted penetrations. The SGF's Work Stream 7 is now investigating the technical viability of these technologies – including their integration and interactions – through a study into the design and operation of GB distribution systems from the present until 2030. The study will highlight the future roles and responsibilities of a Distribution Network Operator (DNO) – perhaps even a shift to them being Distribution System Operators (DSOs) – as well as new requirements in the areas of commercial and regulatory frameworks, skills, facilities and partnering opportunities.

This paper provides an overview of this project, and is structured as follows: first, the study methodology and its main elements are introduced; each of the study elements is then described in detail within a dedicated section; and then the paper ends with conclusions about the expected value of the study results and the next steps to be taken.

It is envisaged that a second paper will be published in due course, which will detail the technical results of the study along with conclusions and recommendations.

STUDY METHODOLOGY

The main elements of the study are outlined below and are described in more detail in the subsequent sections:

- **Scenarios**: two different pathways for the development of energy supply and demand within GB from 2014 to 2030.
- **Base Networks**: these are four models that are representative of particular GB distribution networks in 2014, such as urban and rural areas.
- **Conventional and Smart Solutions**: a number of different interventions that can be applied within the networks to alleviate network issues.
- **Key Issues**: the study will inform 24 Key Issues, covering operational, planning, commercial and regulatory aspects.
- **Use Cases**: the Use Cases describe the modelling and analysis required in order to deliver relevant outputs that address the Key Issues.

As shown in Figure 1, the study methodology takes each Base Network and evolves it to 2030 through a number of time steps. For each time step, generation and demand defined within the Scenarios are applied and their impacts on the networks analysed to identify any issues, using steady-state and dynamic studies, as defined in the Use Cases. Solutions that can mitigate the issues are then applied to the networks, and their impacts analysed. The methodology iterates between evolving a network to the next time step, identifying issues and applying appropriate Solutions, in order to determine credible network development paths. The outputs of the studies, as defined in the Use Cases, are analysed in order to address the Key Issues.

SCENARIOS

Two Scenarios are being considered for this project, which give projected changes in demand and generation. The Scenarios are intended to "stress test" the networks and comprise the following components:

- The uptake of Low Carbon Technologies (LCTs) within the distribution network, driven by the electrification of heat and transport allied with increases in distribution generation. The

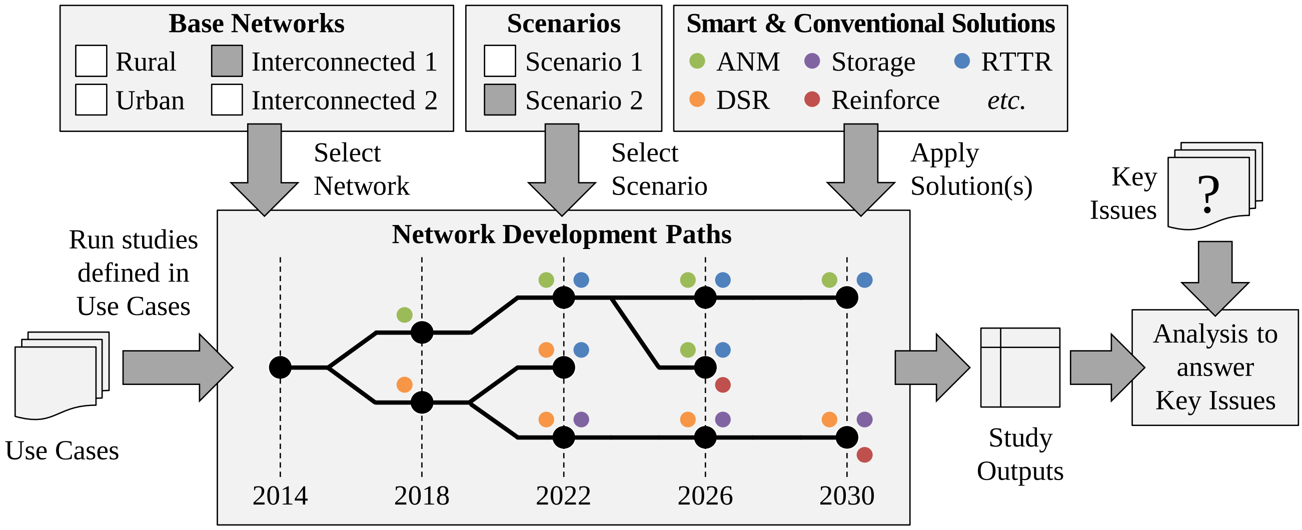

Figure 1 – Overview of the study methodology

following LCTs are considered in the Scenarios:

- Electric Vehicles (EVs)
- Heat Pumps (HPs)
- Photovoltaics (PVs)
- Wind generation
- Biomass generation

- The mix of transmission-connected generation.
- Underlying growth of non-LCT load.

One Scenario is dominated by demand growth owing to a high uptake of EVs and HPs. This Scenario has significant amounts of transmission-connected renewable generation but the uptake of renewables within the distribution network is low.

The second Scenario is dominated by a strong uptake of generation LCTs within the distribution network. The uptake of EVs and HPs is less than that in the first Scenario, and the transmission-connected generation mix has more low carbon generation such as nuclear and coal with carbon capture and storage, rather than renewables.

BASE NETWORKS

Each Base Network represents actual GB distribution network configurations and has been developed from data supplied by one or more GB DNOs. The networks that each model represents have been selected as their arrangements are typical of those found throughout GB and thus conclusions and results from the analysis performed on the Base Networks can be characterised for extrapolation across GB distribution networks.

The general structure of the Base Network models is shown in Figure 2. Each model represents all the voltage levels within a distribution network, from the connection to the transmission network at 132 kV, down to individual Low Voltage (LV) customers.

Within the models, typically only a single network at each voltage level is represented in detail. The networks consist of all the circuits emanating from a particular upstream substation (e.g. all the 33 kV circuits from a 132 / 33 kV substation) and all the substations that the circuits connect to (e.g. 33 / 11 kV substations). The transformation at each downstream substation is represented, although only one will have a detailed network represented below it (e.g. all 11 kV circuits below one 33 / 11 kV substation only), with the rest being represented by lumped equivalents.

The Base Network models were developed in DIgSILENT PowerFactory [3] from multiple data sources, and shall be made publicly available for download from the ENA Smarter Networks Portal [4].

Rural Base Network

Within the Rural Base Network there is a radial 132 kV network with one detailed 33 kV network below it, which features a ring with a radial circuit feeding a detailed 11 kV network. The 11 kV network is radial, though it can be backfed from two directions, and feeds mainly pole-mounted 11 kV / LV distribution transformers. One of the distribution transformers feeds a fully represented radial LV feeder, which includes sections of aerial bundled conductor. The LV feeder has full, three-phase modelling of all LV-connected customers.

Urban Base Network

The Urban Base Network features rings at 132 kV and 33 kV, with radial networks at 6.6 kV and LV. The circuits at 33 kV and below are predominantly constructed from cable, typical of urban areas. The 6.6 kV / LV distribution transformers are ground mounted, and below one is a fully represented LV cable network supplying almost 300 residential customers, with 4 "tapered" feeders whose conductor size reduces along their length.

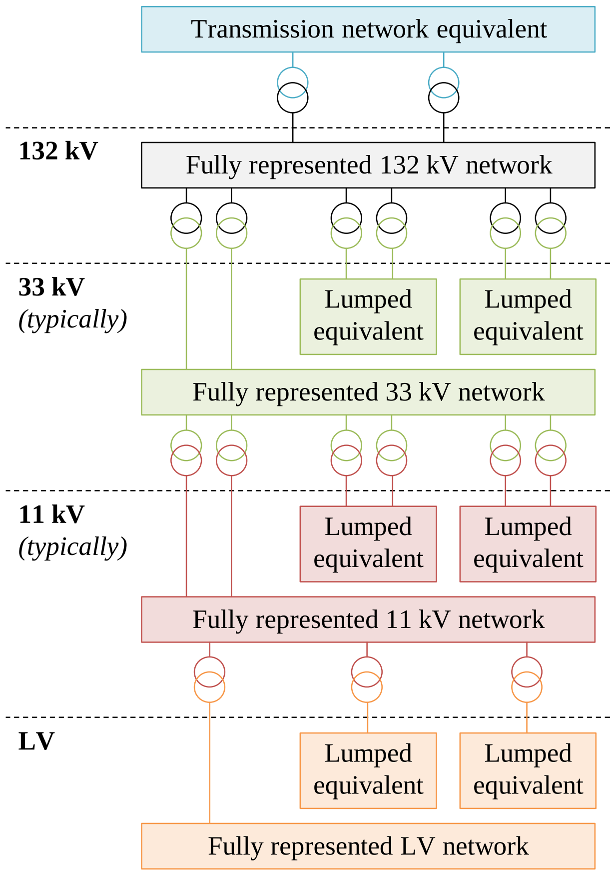

Figure 2 – General structure of the Base Network models

Interconnected Base Networks

Two Base Networks with different types of interconnection have been developed for this project. One features meshing within each voltage level, from 132 kV down to LV. The most distinct feature is meshed single-transformer substations that are supported from adjacent locations. The other Interconnected Base Network is radial at the higher voltage levels (132 kV and 11 kV, with no intermediate 33 kV network) with meshing between groups of LV circuits.

The Interconnected Base Networks represent legacy meshed networks existing in GB. Although these types of network are currently less prevalent, they could become more common as interconnection is considered as a solution to overcome issues in radial networks. Understanding how the legacy meshed networks are expected to operate in the face of future conditions – in particular their resilience, the complexity of their protection, their high fault levels and high reliability – will help inform the application of interconnection within existing radial networks. Meshing of existing radial networks will enable spare capacity to be accessed, and is expected to be assisted by advances in control and communications and the use of power electronics to control power flow.

Transmission Equivalent

To enable whole-system studies that understand the interaction between transmission and distribution, National Grid has provided a model representing a reduced form of the GB transmission network. When combined with distribution network models, studies such as real power balancing and frequency stability can be conducted, although the effect on specific transmission circuits will not be simulated. These whole-system studies will be crucial in analysing the future role of DNOs within the GB-wide power system.

CONVENTIONAL AND SMART SOLUTIONS

Solutions Considered

As the Base Network models are evolved towards representing distribution networks of 2030, various Solutions will be modelled within them to mitigate issues that arise, and will highlight the benefits and impacts of the Solutions. Following on from the previous work of the SGF's Work Stream 3, a set of Smart and Conventional Solutions will be considered. The Conventional Solutions include interventions such as network reinforcement and load transfers between feeders, whereas the Smart Solutions include technologies such as:

- Active Network Management (ANM): this includes dynamic reconfiguration of the network, redirecting power flows to alleviate voltage, thermal and fault level constraints.
- Electrical Energy Storage: storing energy at times of plentiful supply, and discharging at times of peak demand, in order to resolve network thermal and voltage issues.
- Fault Current Limiters: devices that can reduce the currents flowing during fault conditions but have minimal impact during normal operation.
- Demand Side Response (DSR): resolving network issues by calling upon customers who are able to vary their load.
- Real Time Thermal Rating (RTTR): using data about real-time ambient conditions to unlock latent capacity in circuits and transformers, allowing for increased power transfer.

For each of the Solutions, consideration will be given to aspects of their operation, such as communication failures, that may have network impacts.

As well as providing network development paths with appropriate Solutions identified, the study will help to understand what mix of enabling technologies – including Information and Communication Technologies (ICT), control systems and monitoring – will be required in order to implement the Solutions.

Modelling of Solutions

Depending on their nature, the Solutions will be modelled directly as elements embedded in the Base Network models within DIgSILENT PowerFactory, such as for Fault Current Limiters, or via external scripting to simulate the Solution's behaviour, such as for the operation of an Active Network Management scheme.

The reliability of Solutions will be studied by introducing appropriate parameters into the DIgSILENT PowerFactory models and performing reliability studies.

KEY ISSUES

The study seeks to answer 24 Key Issues that are directly relevant to the GB electricity industry, but are also relevant more widely. The Key Issues were identified by the SGF's Work Stream 7, and cover a range of areas, including operations, planning, commercial and regulatory. They also explore the future roles and responsibilities of a DNO in GB.

The 24 Key Issues can be split into 4 groups:

- **Network challenges**: these Key Issues focus on the technical impacts within distribution networks, such as managing voltages and thermal capacity, protection strategies, and understanding the risk and reliability profile of networks to 2030.
- **Active customers**: drawing on customers – both demand and generation – to alter their power draw or injection could enhance system operation and security. Key Issues on this topic address questions such as how much consumer response would be beneficial, how reliable the response would be, and what the potential impacts of customer response are.
- **Whole system challenges**: these Key Issues tackle concerns that are not isolated to distribution networks, but that have a wider impact within the whole electricity system. For example, how will active power balancing and frequency control be achieved? Will DNOs take part in the management of dynamic and transient behaviours, particularly during system emergencies?
- **Additional questions**: these wide-ranging Key Issues cover areas that are not addressed elsewhere, such as requirements for ICT, implications for standards and practices, and the impacts of disruptive technologies.

USE CASES

The concept of a "use case" is used in a number of domains, particularly software engineering, where it is used to describe the interactions between a system and various "actors" (such as users of the system) in order to achieve a specific goal. Use cases describe the interactions at a high level, and are useful when elucidating specifications for the system and the interactions, including any associated processes.

In this project, a *Use Case* defines high-level activities that are used to derive quantitative and qualitative outputs that form the basis of analysis to answer one or more Key Issues. The set of Use Cases helps to ensure that each of the Key Issues has been addressed within the project, and that each Key Issue is explored to the appropriate depth of detail. Although the Use Cases for this project are not completely analogous to the use case concept as used in software engineering – to aid differentiation, they are referred to as *Project Delivery* Use Cases within the project – a similar structure is used, with each Use Case including the following details:

- **Category**: either "Network Analysis", where detailed network studies are required to derive the outputs, or "Wider System Assessment", where the analysis has a more qualitative nature.
- **Objective / Goal**: a short description of what is to be achieved by the Use Case.
- **Description**: a brief summary of the Use Case's processes and how they link with the outputs.
- **Responsible Consortium Party**: who is under-taking the processes described in the Use Case.
- **Pre-conditions**: conditions to be fulfilled before the Use Case can proceed.
- **Networks / Scenarios**: the Base Networks and Scenarios that the Use Case are applicable to.
- **Assumptions**: conditions, data and processes assumed for the Use Case.
- **Tools**: the commercial software, bespoke software and scripts, and other materials (e.g. spreadsheets) required to implement the processes described in the Use Case.
- **Process (flow)**: a description of the steps taken within the Use Case to derive the outputs in order to meet the Objective / Goal; this may include studies such as load flow, fault level or reliability analysis, or other processes such as searching and analysing appropriate literature.
- **Key Issues**: the Key Issues that the Use Case seeks to address through its Objective / Goal.
- **Outputs**: a description of the qualitative and quantitative outputs from the Use Case, which are used to meet the Objective / Goal and address the applicable Key Issues.

In total, 13 Use Cases have been developed for this project and these are listed in Table 1. Each Use Case covers a particular subject area, typically a specific study type, which may cut across a number of the Key Issues. In the current stages of the project, the Use Cases are being applied to derive outputs, which will be analysed in the final stage of the project to address the Key Issues.

Table 1 – Use Cases

Network Analysis	Wider System Assessment
Understanding Future Steady State Operation	Providing Adequate Future Protection
Examining Constraint Management	Transform Comparison
Managing System Fault Levels	Facilitating Consumer Response
Managing System Dynamic Performance	Assessing Future Monitoring / Communication Requirements
Ensuring Adequate Frequency Response & Balancing	DNO / DSO Business Activities
Meeting Power Quality Requirements	Industry Context
Understanding Future System Reliability and Risk	

CONCLUSIONS & NEXT STEPS

This project will provide insight into how distribution networks will operate in 2030. Although this project is focused on GB distribution networks, the findings that will be produced are expected to be more widely applicable as many of the same challenges will be faced worldwide and many of the same solutions will be considered to overcome these challenges. Furthermore, the study methodology may be usefully adopted by others, particularly the idea of utilising use cases to ensure that a project with such a large scope delivers relevant outputs across a range of topics.

This paper has introduced the study and its elements. Amongst these, the Base Networks shall be made publicly available and should act as a useful resource for those studying the future development of distribution networks. The Base Networks are currently being evolved to represent networks to 2030, and the detailed studies of these networks are being undertaken. Following completion of the studies, the results will be analysed to address the Key Issues, and the output of this process will be reported during the latter half of 2015.

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