MODELLING THE TRANSITION TO DISTRIBUTION SYSTEM OPERATOR USING THE SMART GRID ARCHITECTURE MODEL

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ABSTRACT

The extent of change towards a decarbonised, decentralised and digitised energy system dramatically alters assumptions about future roles and business models for network companies. Distribution Network Operators (DNOs) need to revisit their current business models and consider their evolution to Distribution System Operators (DSOs). In the UK, Energy Networks Association's (ENA) Open Networks Project (ON-PRJ) has defined the key functional capabilities required by the future DSO and developed five market model options capable of supporting the smart decentralised energy industry that the DNO is transitioning towards. This paper presents an innovative methodology for the practical implementation of the Smart Grid Architecture Model (SGAM) to represent alternative holistic model options for the DSO of the future by describing the business and functional specifications associated with them, and by visually representing the architecture of the smart grid system that underpins them. The methodology developed provides a structured and coherent way to describe, visualize and interpret possible model options for the DSO and enables a methodical comparison between holistic models on a like-for-like basis.

INTRODUCTION

The power sector is witnessing considerable disruption, transforming the way energy stakeholders think about, produce and use electricity. This transformational change towards a decarbonised, decentralised and digitised system is profound and DNOs are right in the frontline of its impacts. The extent of change in the sector dramatically alters assumptions about business models and future roles for network companies. This means that DNOs need to revisit their current business models and consider their evolution to DSOs. This transition process will enable them to adapt to meet the disruption challenges and to realise associated opportunities whilst maintaining low cost and reliable energy distribution for customers.

In the UK, the ENA's ON-PRJ [1] has defined the functional capabilities of the DSO of the future considering the various technical, commercial and regulatory aspects inherent to the life cycle of network businesses. Five holistic model options have been developed capable of supporting the smart decentralised energy industry that the DNO is transitioning towards. This work has expedited the delivery of real-world trials on the creation of markets for network flexibility that enable flexibility services to compete alongside traditional investment options for all relevant network reinforcements decisions in the future.

To this end, the paper first presents the definition, roles and responsibilities of the future DSO that have been identified and defined by the ON-PRJ. It then summarises the key functional capabilities required by a DSO to develop and operate the distribution network. It introduces one of the model options from the project, 'DSO Coordinates', for the future DSO to operate in that supports its definition and functional capabilities. The paper then presents an innovative methodology for the practical implementation of the SGAM [2] to represent the market model 'DSO Coordinates' by describing the business and functional specifications associated with it, and by visually representing the architecture of the smart grid system that underpins it. The description of the methodology is complemented with a step-by-step real-world case study applied to a specific functional requirement of the DSO within the 'DSO Coordinates' future option.

The methodology developed provides a structured and comprehensive way to describe, visualise and interpret the possible model options for the DSO of the future, by capturing the interactions between different actors from a high-level business context down to detailed data transactions between parties and associated communications methods between equipment. This methodical approach also enables a like-for-like comparison between holistic models.

MARKET MODEL OPTIONS FOR THE DSO

Definition of the DSO

The ON-PRJ has defined DSO as: "A DSO securely operates and develops an active distribution system. As a neutral facilitator of an open and accessible market it will enable competitive access to markets and the optimal use of distributed energy resources (DER) on distribution networks to deliver security, sustainability and affordability in the support of whole system optimisation. A DSO enables customers to be both producers and consumers; enabling customer choice through access to networks and markets" [3].

Functions of the DSO

This work has identified and defined the key capabilities

required by a DSO to plan and operate the distribution network following an Active Distribution System Management approach and to progress towards a DSO business structure. These capabilities are described via 8 'functions' which are split into 44 'activities' that support them, with activities further split into small 'processes' in order to define the DSO transition in a modular and structured manner.
The main functions and activities of the DSO are comprehensively explored in [4] and are named as: system coordination; network operation; investment planning; connections and connection rights; system defence and restoration; services / market facilitation; service optimisation; and charging.

Holistic model options for the DSO of the future

This work has explored five holistic model options for the DSO of the future that are broadly characterised by: the extent to which the DSO accesses DER, facilitates services and markets and provides own services to network customers; the extent of its relationship with the ESO and market participants; and the associated market arrangements. The five models or 'Future Worlds' are extensively examined in [5], [6] and are listed as: DSO Coordinates; Coordinated DSO-ESO procurement and dispatch; Price-Driven Flexibility; ESO Coordinates; and Flexibility Coordinator(s).

Future world: DSO Coordinates

For this paper we will be explicitly exploring the 'DSO Co-ordinates' world which is defined below.
The DSO procures and activates DER for distribution network constraint management and for providing services to the ESO for regional and national requirements. The DSO also schedules flows to and from the electricity transmission system based on a predefined power exchange schedule agreed with the ESO. From a transmission network perspective, the DSO behaves in a similar manner to other transmission connected parties and the services it can provide from DER connected within its networks are evaluated on a regional transmission and national level by the ESO in a non-discriminatory manner along with other transmission connected service providers. The DSO and the ESO actively exchange information to maximise synergies between transmission and distribution network service requirements and to minimise potential conflicts associated with the delivery of concurrent services.

METHODOLOGY AND CASE STUDY

SGAM

The SGAM [2] is a holistic framework for describing smart grid systems, from their business and functional specifications right through to their architectural design as illustrated in Figure 1.
The SGAM is represented by a three-dimensional framework structured into five 'interoperability layers' which represent, from top to bottom: business models, functional requirements and specifications, information exchange, communication protocols and components. The 'domains' reflect the electrical energy conversion chain physically relating to the electrical power grid. The 'zones' characterise the hierarchy of power system management distinguishing between electrical process and information management viewpoints.

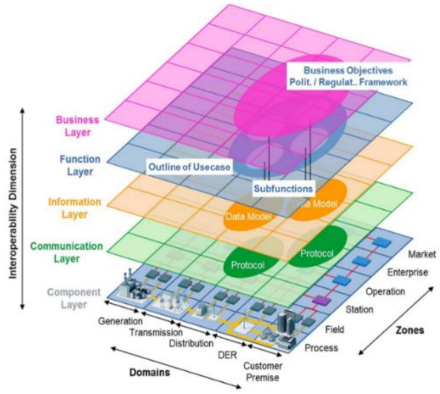

Figure 1: Smart Grid Architecture Model

SGAM development methodology

This work developed an innovative methodology for the practical implementation of the SGAM to represent the model for the DSO of the future by describing the business and functional specifications associated with it and by visually representing the architecture of the smart grid system that underpins it. The methodology developed provides a structured and coherent way to describe, visualize and interpret potential holistic models for the DSO of the future by capturing the interactions between different actors from a high-level business context down to the detail of what information is exchanged using what communication methods between physical components / equipment. This methodical approach also enables a like-for-like comparison between different models. Figure 2 depicts a representation of the methodology for the development of SGAM.

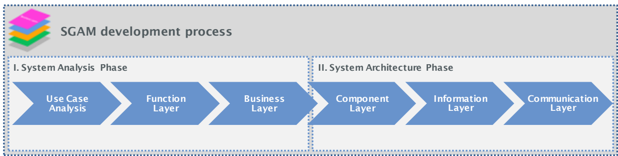

Figure 2: Methodology for the development of the SGAM

The methodology is constituted of two distinct phases: system analysis and system architecture. The system analysis phase defines scope and objectives of the system of interest and its functional requirements. The focus is on the required functional specification rather than on technical solutions. The system architecture phase maps the functional requirements of the system into a high-level architecture. This architecture describes the main subsystems and their interactions without detailing their inner composition.

Use Case Analysis

The application of the methodology for the development

of the SGAM is undertaken through 'Use Case Analysis' whereby each of the DSO model options is selected and analysed in detail.
In this paper, Use Case Analysis will be demonstrated on a real-world 'use case' within the 'DSO Coordinates' future option. The selected use case is described by the following characteristics:

- *DSO future world*: 'DSO Coordinates';
- *DSO function*: 'Network operation';
- *DSO activity*: 'Operate network within thermal ratings';
- *DSO process*: 'Activation of DER for distribution network thermal constraint management'.

The use cases have been developed in detail through a series of energy industry workshops to ensure they take a whole system view and represent the impacts on a range of stakeholders. The entire SGAM representation of the market model option 'DSO Coordinates' is presented in detail in [7].

System analysis phase

In the system analysis phase, the model identifies and defines the 'business actors' involved in the DSO market model for each use case, their individual business goals and their relationship with other business actors, in turn establishing the Business Use Case (BUC) needed for the business actors to realise their individual goals.
For each use case, the BUC invokes a High-Level Use Case (HLUC) and Primary Use Case (PUC) that together describe the functional requirements necessary to fulfil the BUC, where HLUCs are defined from the DSO functions and PUCs are defined from the DSO activities.
Together, these elements construe a 'Use Case Diagram' as portrayed in Figure 3 for the use case under analysis in this paper.

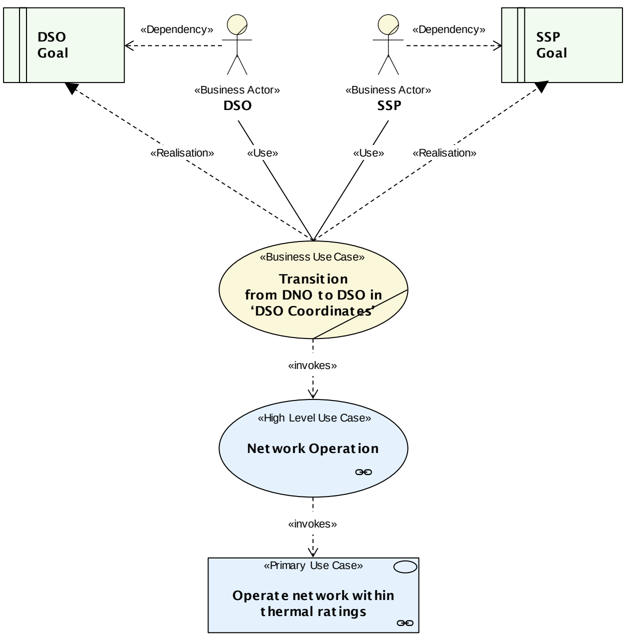

Figure 3: Use Case Diagram for 'operate network within thermal ratings' use case

Specific elements in Figure 3 are described in further detail within Table 1.

Table 1: Use Case Definitions

Business actors and business goals
There are two business actors involved in the example used in this paper. The 'DSO' business actor has been previously defined in this paper. The other business actor is the System Service Providers (SSP). These are small-scale power generation technologies and larger end use electricity consumers with the ability of flexing their demand, that are directly connected to the electricity distribution network. The SSP provide flexibility services to SOs (e.g. ESO, DSO) for electricity system balancing and network constraint management [8]. Their business goal is to establish commercial relationships with SOs to derive revenue from the provision of flexibility services.
BUC: Transition from DNO to DSO within the future world DSO Coordinates
The extent of change towards a decarbonised, decentralised and digitised system dramatically alters assumptions about future roles and business models for network companies. DNOs need to revisit their current business models and consider their evolution to DSO within the DSO Coordinates world.
HLUC: Network operation
Operate the electricity distribution network to maintain a safe and secure system robust against credible events such as circuit trips and generation loss. Coordinate and collaborate with the ESO to manage potential conflicts to support whole system optimisation.
PUC: Operate network within thermal ratings
Use network asset rating and power flow information to operate local distribution network assets within ratings.

Further developing each use case, the 'Function Layer' defines the functional specifications of the DSO world that are required to deliver the BUC. To achieve this, business actors are transformed into 'logical actors', as the physical realisation of the functional specification involves logical decisions and evaluations. For example, within different use cases, the DSO may be transformed into a number of logical actors, including 'Customer Portal'. This 1:*n* 'model transformation' between business and logical actors creates separation between business and functional activities from a modelling perspective rather than a physical one. The PUCs and respective logical actors are then mapped onto the function layer grid. The 'Business Layer' then simply maps the HLUCs onto the business layer grid as is described in further detail below.

Function layer

The function layer defines the functional specification of the DSO world that is required to deliver the business objectives of each use case. Figure 3 and Table 1 describe the use case under analysis in this paper where a HLUC

and PUC are used to describe the DSO functions and activities, respectively.
The functional specification of the PUC 'operate network within thermal ratings' with respect to the process of 'distribution network thermal constraint management' was captured in the industry workshops and is displayed through an 'activity diagram' in Figure 4.

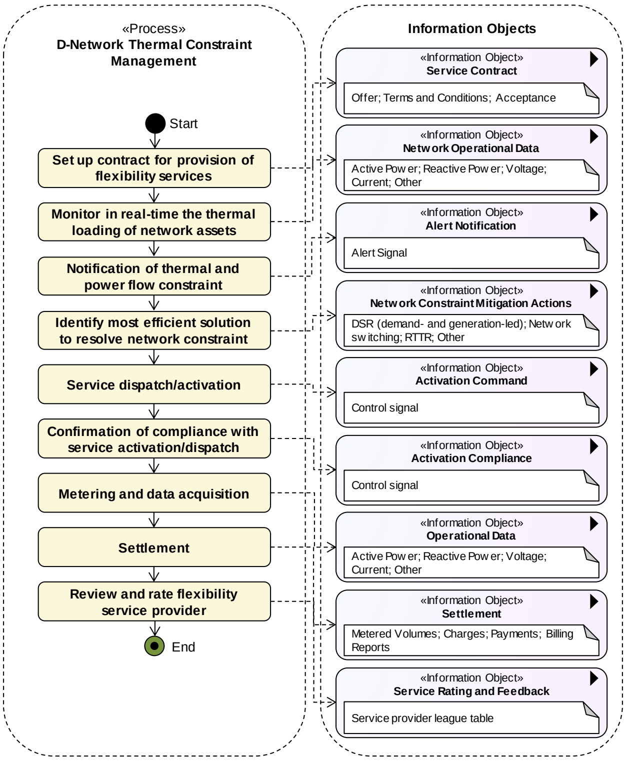

Figure 4: Activity diagram for 'distribution network thermal constraint management'

The activity diagram in Figure 4, developed using Sparx Enterprise Architect software, describes the functional steps required to realise a single process within the PUC. It also assigns 'information objects' to the functional steps to characterise the information that is being exchanged for each step in the process.

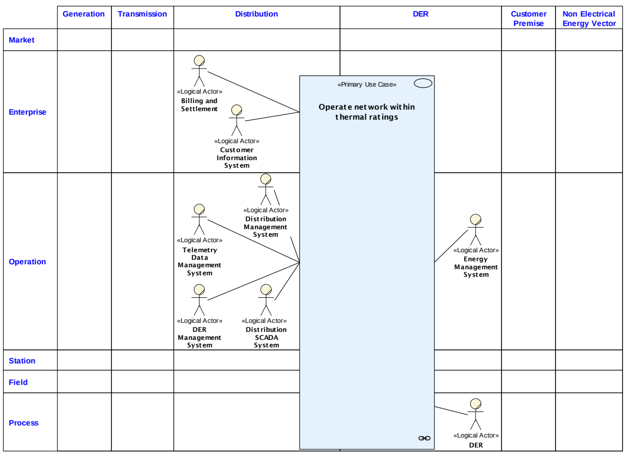

Figure 5: Function layer for 'distribution network thermal constraint management'

The function layer spatially distributes all PUCs (i.e. DSO activities) involved in a HLUC (i.e. DSO function) across the SGAM smart grid plane. Figure 5 shows the function layer for the use case under analysis only.

Business layer

The business layer is modelled to represent the DSO functions per DSO world. As such, all HLUCs (i.e. DSO functions) are spatially distributed across the smart grid plane for every BUC (i.e. DSO world). Figure 6 illustrates the business layer grid for the market model option 'DSO Coordinates'. As can be seen there are 8 HLUCs per world, corresponding to the 8 DSO functions.

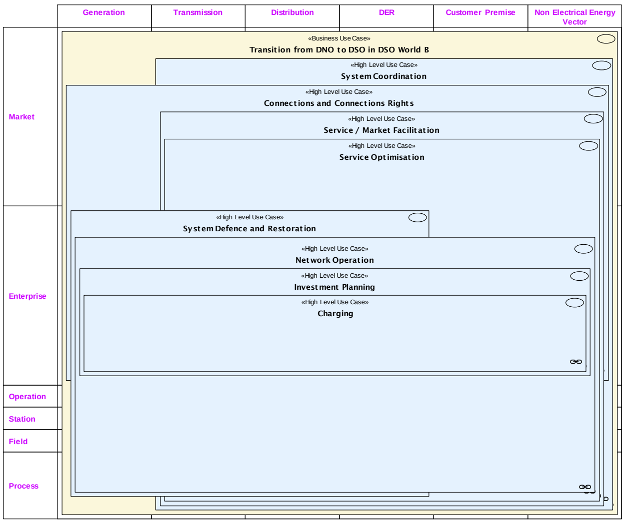

Figure 6: Business layer

System architecture phase

Overview

The system architecture describes the key functionality of the main subsystems / components and their interactions without detailing their inner composition. Thus, the system architecture can be interpreted as a black box model of all involved subsystems / components with the form of the interactions between them being the key difference and focus across the component, information and communication layers.

Component layer

The 'Component Layer' directly maps the functional requirements of the system into a high-level architectural solution by transforming logical actors into the 'physical components' which must exit to realise the logical actors and distributing these physical components onto the component layer grid. This layer also focusses on the physical connections between components by identifying the general network topology and ICT network architecture. Figure 7 introduces the component layer of the use case under analysis.

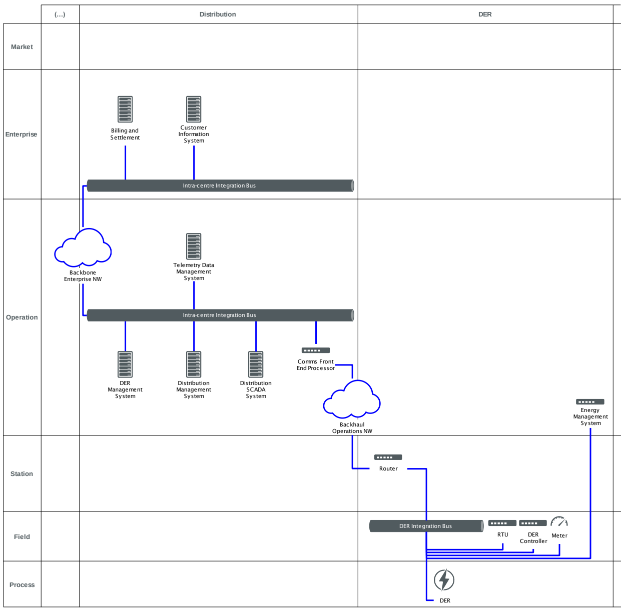

Figure 7: Component layer grid for 'distribution network thermal constraint management'

Information layer

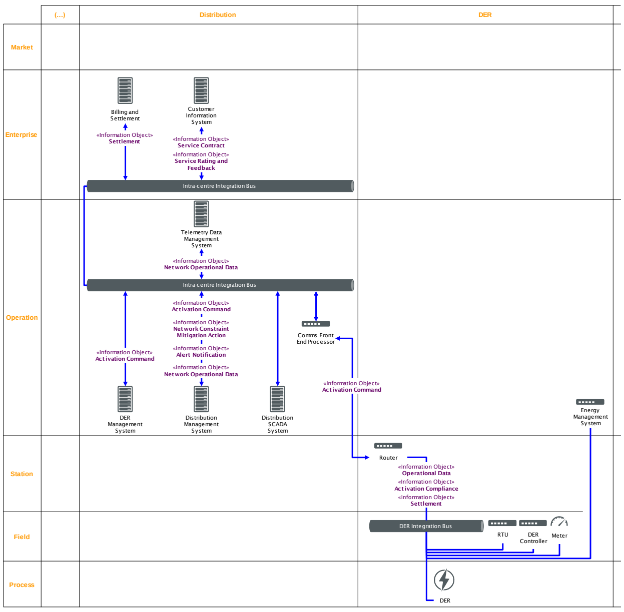

Figure 8: Information layer grid for 'distribution network thermal constraint management'

The 'Information Layer' specifies the information or data being exchanged between components. To do this 'information objects', developed within the activity diagram for each process, as shown in Figure 4, are used. These information objects are mapped onto the information layer grid across the relevant physical components. Figure 8 displays the information layer for the use case under assessment.

Communication layer

The 'Communication Layer' defines the types of communication (i.e. protocols used for communication) that ought to exist to enable information objects being exchanged between components. These communication types are subsequently mapped onto the communication layer grid between the relevant physical components in a similar manner to that of the information layer. This allows differentiation between 'classes' of communication that were defined through industry workshops, such as 'real-time' (SCADA) and longer-term contractual relationships.

CONCLUSIONS

The paper introduced the definition, roles and responsibilities of the future DSO that have been identified and defined by the ENA's ON-PRJ. As a case study, it introduced a holistic model option, 'DSO Coordinates', for the future DSO to operate in that supports its definition and functional capabilities. It summarised the key functional capabilities required by a DSO to develop and operate the distribution network following an active distribution system management approach.

Using the use case example of 'distribution network thermal constraint management', the paper presented an innovative methodology for the practical implementation of the SGAM to represent alternative model options for the DSO of the future by describing the business and functional specifications associated with them, and by visually representing the architecture of the smart grid system that underpins them. The methodology developed provides a structured and coherent way to describe, visualize and interpret possible future model options for the DSO and enables a methodical comparison between models on a like-for-like basis.

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