



PSA Model Development

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With thanks to the following contributors:



Contents

List of Acronyms and Abbreviations	3
Executive Summary	4
1 Introduction	8
2 PSA Model Requirements for TRANSITION	18
3 Model Development Process	26
4 Data Requirements	36
5 Network Model Validation and Maintenance	47
6 TRANSITION PSA Workflow During Flexibility Trials	60
7 Key Learnings and Conclusions	66
8 Future work	68
References	70

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List of Acronyms and Abbreviations

ACO	-	Automatic (Auto) Change-Over
ANM	-	Active Network Management
AVC	-	Automatic Voltage Control
BAU	-	Business as usual
BSP	-	Bulk Supply Point
CIM	-	Common Information Model
CGMES	-	Common Grid Model Exchange Standard
DNO	-	Distribution Network Operator
DSO	-	Distribution System Operation
EHV	-	Extra High Voltage (132 and 33kV in the TRANSITION trial area)
ENTSO-E	-	European Network of Transmission System Operators for Electricity
EO	-	Electric Office
ESO	-	Electricity System Operator
GIS	-	Geographical Information System
GML	-	Geographical Markup Language
GSP	-	Grid Supply Point
HV	-	High Voltage (11kV in the TRANSITION trial area)
LEO	-	Local Energy Oxfordshire
LCT	-	Low Carbon Technologies
LV	-	Low Voltage (0.4kV and 0.23kV in the TRANSITION trial area)
MEC	-	Maximum Export Capacity
NMF	-	Neutral Market Facilitator
P2P	-	Peer-to-peer
PSA	-	Power System Analysis
SEPD	-	Southern Electricity Power Distribution
SFN	-	Smart and Fair Neighbourhoods
SLD	-	Single Line Diagram
TCV	-	Total Contract Value
TP	-	Trial Period
XML	-	Extensible Markup Language
	-	
WSC	-	Whole System Coordinator

Executive Summary

This report summarises the background use-cases, process, results, and key learnings related to the development of the Power System Analysis (PSA) models used in TRANSITION.

Project TRANSITION is a 5-year Ofgem NIC funded project aiming to trial and demonstrate new systems and tools for flexibility market deployment at scale, and to support the transition to Distribution Systems Operation (DSO). TRANSITION works closely with Project LEO (Local Energy Oxfordshire)¹, which is a 4-year Innovate-UK funded project that along with TRANSITION² is running trials in Oxfordshire to build a broad range of reliable evidence of the technological, market and social conditions needed for a greener, more flexible, and fair electricity system at local level.

These flexibility market trials will cover an area of the SSEN's SEPD license area in Oxfordshire, specifically covering 13 Primary Substations that are spread across 6 Bulk supply Points (BSPs).

An accurate and well-maintained PSA model is critical across all process stages of DSO procured flexibility services – from the initial needs analysis, subsequent contract selection, dispatch, and real-time system monitoring. Because the underlying drivers that the flexibility service are seeking to manage are all directly related to actual or potential network constraints, then the flexibility markets must be grounded in a solid representation and understanding of the network issues and the models required to study and represent them.

It is also important to make a distinction between:

- a PSA **Model**, which is the collection of various data sets for input to/output from the single snapshot PSA analysis and
- the PSA **Tool**, which is the software suite used to perform the calculations on a given model (e.g., DlgSILENT PowerFactory or Siemens PSS®E or Opus One GridOS).

In the context of this report, the challenges of both a **PSA model** and the **PSA tools** are important to address and are covered in detail. The functional place of the PSA tool and model in the overall TRANSITION architecture design are summarised in Figure 1.

Following the “flexibility first” principle to manage network issues in the present and future regulatory framework, then it is likely that there may be active constraints in a widespread manner across the system, and at all voltage hierarchy levels of the DSO networks. This will therefore also require active participation of flexibility providers at all levels of the network; not just the EHV connected assets of traditional markets, but also sources of flexibility at the grid edge. Project LEO is focussed on enabling such ‘small and many’ resources for flexibility market participation.

In terms of implications of this for PSA network modelling tasks in the future, this will likely need the development of models that capture, in an *integrated* manner, the network issues at several voltage hierarchy levels simultaneously (see diagram in Figure 2). Bringing together modelling issues at EHV level (132 and 33kV in the TRANSITION/LEO trial area), along with HV (11kV in the TRANSITION/LEO trial area) and potentially LV as well, requires an approach that merges traditionally separate models, tools, processes, data sets, internal DSO organisational teams, and necessary technical engineering assumptions.

¹ [Home - Project LEO \(project-leo.co.uk\)](http://project-leo.co.uk)

² [SSEN Transition \(ssen-transition.com\)](http://ssen-transition.com)

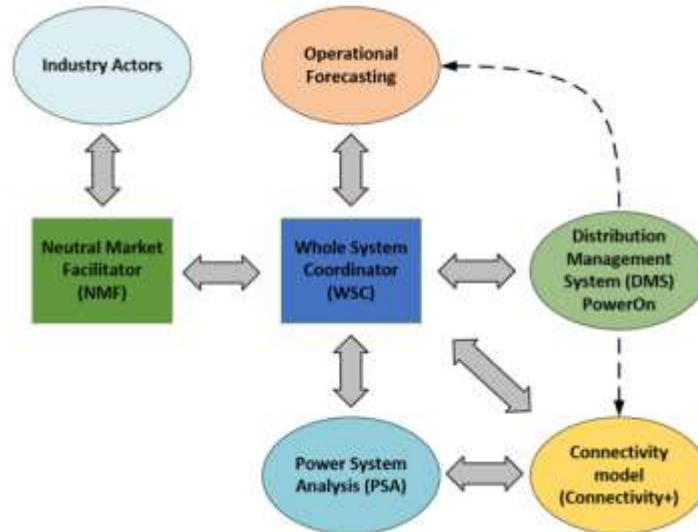


Figure 1. Overview of systems used in TRANSITION and their interfaces

With the growing interest in also bringing flexibility market activities closer to real-time (for both contracting and dispatch), then this may also furthermore require the PSA model development to *merge issues that were traditionally separable between Planning and Operations timeframes.*

Additionally, the growing interest in bringing flexibility market activities closer to real-time (for both contracting and dispatch), this may also require the PSA model development to *merge issues that were traditionally separable between Planning and Operation timeframes.*

The PSA models and tools that were developed and deployed in the TRANSITION/LEO modelling work have been required to merge all these perspectives (multiple voltage hierarchies, and different timeframes of analysis), so that functioning and scalable flexibility market processes can be supported.

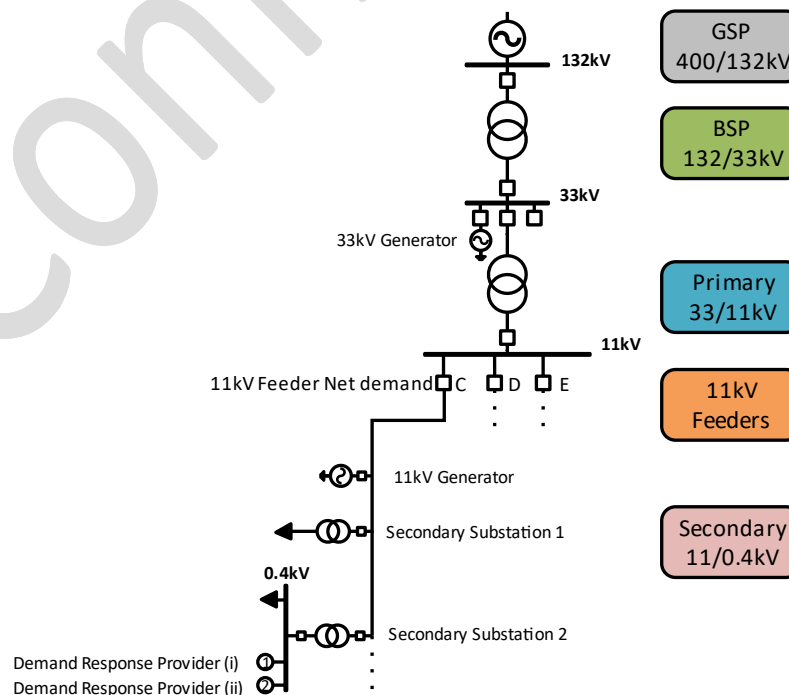


Figure 2. Distribution network hierarchy as a simplified single line diagram (132/33/11kV)

Developing these types of PSA models has required a huge amount of data gathering, data integration and validation, version control and maintenance, from a wide range of internal and external sources. Specific processes for data element naming and power flow sign convention were established so that the PSA models, when used and integrated with other dependent follow-on flexibility market processes and tools, could allow overall process consistency and efficiency.

A particular focus of the model development in this respect was around the use and processing of Common Information Model (CIM) input data. The CIM format enabled PSA model integration of various input data processes (sometimes with different CIM versions and profiles) and ensured overall PSA model interoperability between different systems and tools (with different CIM adapters and translations) could be achieved.

The work was led by SSEN, with DigSILENT PowerFactory as the key model development 'anchor' PSA tool, but with very important technical collaboration and resource input from RINA Consulting, Open Grid System (OGS), and Opus One, as well as a very wide range of internal SSEN BAU subject matter experts and stakeholders.

A summary of the key process steps that were conducted in the model development would be as follows:

- Taking the 11kV/HV network connectivity data (in CIM v15 format) from our GIS system Electric Office, by virtue of the adjacent SSEN Connectivity+ project outputs
- Converting those 11kV/HV datasets in the OGS Cimphony tool from CIM v15 to CIM v16 (CGMES version 2.4.15 profile), with the inclusion of electrical parameters and asset ratings and other miscellaneous corrections
- Importing 11kV/HV CIM v16 datasets in to PowerFactory using the relevant CIM adapter
- Receiving the EHV PSS[®]E model as a raw data file, and reading that into PowerFactory using the relevant import adapter
- Merging the EHV and HV datasets in PowerFactory to develop the integrated model (each BSP was modelled as a standalone model to match the different flexibility market constraint zones assumed for the purposes of these trials)
- The relevant network circuit-breaker and switching points were added to the EHV model in PowerFactory, to allow representation of topology changes in operational timeframe when performing power flow analysis
- Relevant demand loading values, and generator objects values were added to the model, including specific representation of flexibility market participant units
- The models were solved for different use cases, with relevant quality control checks
 - As these single snapshot models would be later deployed in 24/7 processes driven by operational forecasting data then stress testing and convergence assessments, across particularly onerous loading levels and contingency scenarios, was conducted to test model robustness
- The model was exported from PowerFactory using the CIM v16 CGMES 2.4.15 profile, and loaded into the TRANSITION Whole System Coordinator (WSC) tool and integration and convergence-tested
- Following successful loading of the model from the PowerFactory PSA tool to the WSC, and merged/fed with operational forecasting data, the technical platform was ready for use in the market trials

A summary of the key learnings from the work completed to date would be as follows:

- Developing integrated models across multiple voltage levels (e.g., EHV and HV combined), that may have been traditionally separate, is likely to be an important factor underpinning widescale PSA model flexibility market analytics in the future
- Good consistency and open availability of high-quality data, coming from, and used within various sources and tools within the DSO business, is critical to scaling the development of these types of PSA models
- CIM interoperability of PSA tools is very desirable, and useful, but is arguably still developing and there is still work to do.
 - Manual, or other automated fixes, were required as part of the CIM transformation and importing processes in this project, with the OGS Cimphony tool being a key solution used in the translation of formats
 - Further work may be needed to ensure CIM profile interoperability for distribution needs at the lower voltage of the network in the future:
 - The present CIM v16 CGMES profile in PowerFactory is presently targeted at EHV analysis, where multi-phase and unbalanced network modelling requirements are usually less relevant
 - With the same CIM version/profile used, the PSA tools may give slightly different results initially, without corrections being put in place to ensure consistency
- The network is constantly evolving in the real world, with operational switching, as well as new developments happening at pace in an ongoing manner. Procedures and processes need to be further evolved to ensure models can stay up to date.
- PSA model data gathering, model development and ongoing maintenance processes may need to be made more efficient, with less manual and more automated processing of the steps followed in this work, to be scalable in future, beyond the area of the Oxfordshire project.

A summary of the next steps in the PSA model development programme of work for medium term horizon can be listed as follows:

- Further development of the integrated model to explore the ability to represent LV networks,
 - considering the degree to which they can be included in the existing EHV/HV integrated model based on trade-offs in the scale/size of the model, or if more likely, there is a natural separation of modelling required between LV and the integrated EHV/HV model
 - determining the degree to which the very different technical attributes of the LV network (where single-phase connections are more common, which then translates into a higher degree of phase imbalance) may require a standalone treatment
- Consider the degree to which other PSA tools, such as PowerFactory, can be reliably deployed in an operational environment
- Further develop and refine the data sets and assumptions used for the models in support of the successive flexibility market Trial Periods 2 and 3

1 Introduction

1.1 Project Background

The GB electricity network continues to evolve, and there is a clear need for networks to adapt, focus more on the development of flexible services, enhance operations, and allow new market models such as peer-to-peer trading to emerge. The ‘fit-and-forget’ approach of traditional network operation relied on predictable energy use and production that matched that use. The transition to DSO (Distribution System Operator) model has the potential to bring significant benefits to customers; it also brings a range of new complex challenges, unintended consequences and risks for market participants, new entrants, and the network licensees.

The ENA Open Networks Project (ON-P) is focussed on defining the DNO transition to a DSO model and has been endorsed by the UK Government’s Smart Systems and Flexibility Plan. TRANSITION is designed to help inform the work of the Open Networks Project in the transition the project will design and demonstrate the tools and practices DNOs will need to adopt to become DSOs as well as trialling the ON-P market models.

TRANSITION is an Ofgem Electricity Network Innovation Competition (NIC) funded project. Led by SSEN in conjunction with our project partners ENWL, CGI, Origami and Atkins.

In addition, the project is also closely collaborating with the Local Energy Oxfordshire (LEO) project, a UK Industrial Strategy funded project. Both TRANSITION and LEO have objectives that are closely aligned and when combined significantly enhance overall learning. Integration with Project LEO significantly enhances testing opportunity and offers insights into the needs of local energy actors.

Projects LEO and TRANSITION, have three consecutive Trial Periods (also referred to TP1, TP2, TP3 in this report), in which growing capability and complexity of the markets, systems and tools will be trialled, with learnings from one period driving the inputs to the next.

For the development of more refined processes for DSO-enabled and DSO-procured flexible services, then some refinements are required to the PSA network models that are used to underpin those activities.

This report will summarise the background use-cases and motivations, the methodological process and the key result learnings related to the development of the Power System Analysis (PSA) models used in Projects LEO and TRANSITION, and their application in the trials.

There are several stages of the processes where the PSA model is required – from the initial needs analysis, subsequent contract selection, dispatch, and real-time system monitoring. Because the underlying drivers that the flexibility service are seeking to manage are all directly related to actual or potential network constraints, then the fundamentals of the flexibility markets must be grounded in a solid representation and understanding of the network issues and the models required to study and represent them.

It is also important to make a distinction between:

- a PSA **Model**, which is the collection of various data sets for input to/output from the single snapshot PSA analysis and
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In the context of this report, the challenges of both a **PSA model** and the **PSA tools** are important to address and are covered in detail.

Flexibility Markets

1.1.1 Flexibility in business as usual (BAU)

At present SSEN procures flexibility services through its Constraint Managed Zone (CMZ) initiative, which was established since circa 2016. A CMZ is a part of the network, in which it is forecasted to have capacity constraints (i.e., the forecasted load would exceed the firm capacity of the substation supplying that network area). This capacity constraint could be due to growth in the load or generation, or because of planned maintenance work. CMZs are used to contract flexibility services to avoid these capacity constraints. SSEN procures four services via CMZs [1]:

- Sustain
- Secure
- Dynamic
- Restore

Sustain service is intended to cover well predicted network constraint scenarios, whereas Secure, Dynamic and Restore are intended to cover various scenarios of maintenance events, contingency outages, abnormal network running arrangements, and customer outage conditions.

For Sustain, SSEN provides a target MW requirement with a defined time window, based on forecasted load growth in a particular are of the network which would have otherwise required reinforcement.

For Secure, Dynamic and Restore, SSEN does not set a cap MW, to increase the range and diversity of contracts to ensure to cover different fault scenarios on the network.

The contracts are usually for multiple years, capped at 5-year maximum.

Building on the progress within the CMZ initiatives, the TRANSITION and LEO innovation projects are looking at procuring and delivering flexibility on a closer to real-time basis.

1.1.2 PSA Use Case and Peer-to-Peer (P2P)

The main use case of the PSA model during the TRANSITION/LEO trials (TRANSITION and LEO used interchangeably hereafter) is to calculate the flexibility requirements of the network and to procure and dispatch this flexibility from industry actors in real-time (or close to real-time depending on the service). A related use case is to perform a network assessment of DSO enabled services such as Peer-Peer capacity trades and potentially ESO procured services. A simple view of the high-level process is illustrated in Figure 3.



Figure 3. High-level process for PSA uses in TRANSITION

TRANSITION will investigate several DSO procured and DSO-enabled services in the trials:

- Sustain Peak
- Sustain Peak Export
- Secure
- Dynamic
- Peer-Peer MIC/MEC connection capacity trading, often also termed Exceeding Mic/MEC in this report (EMM)
- Peer-Peer Offsetting (whereby demand and generation counteract each other behind a constraint)
- ESO/DSO Coordinated Services procurement (e.g., considering potential conflict management between an ESO STOR service procured in the same part of the distribution network as a DSO service)

To achieve all of this, four main systems are used in the TRANSITION project: the Whole System Coordinator (WSC), the Neutral Market Facilitator (NMF), the Power Systems Analysis (PSA) tool/model and the Operational Forecasting engine. An overview of how these systems interact is provided in Figure 4.

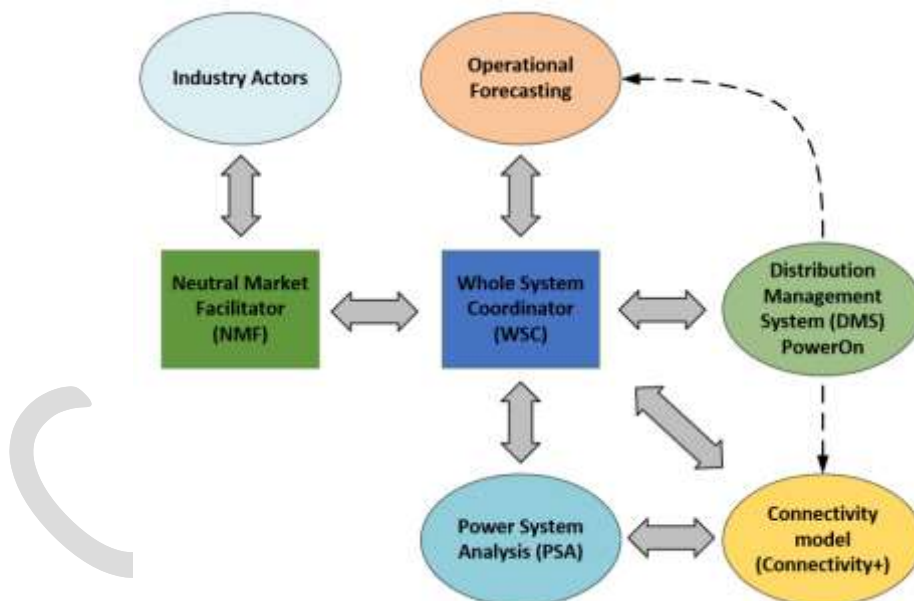


Figure 4. Overview of systems used in TRANSITION and their interfaces

The PSA tool hosts a model of the network and can perform power flow and optimal power flow (OPF)³ calculations, which identify network constraints. The PSA is also used to monitor the impact of any flexibility dispatch.

³ There is a subtle but important sub-categorisation of two types of PSA studies that can be conducted, namely:

The Operational Forecasting engine provides nodal demand and generation forecasts on a 4–10-day horizon, which are used as input into the PSA tool to run power flow analysis.

The NMF is a customer facing market platform that allows interested parties and industry actors to register their interest in participating in the flexibility market. Hence, the NMF holds a database of the available flexibility assets and their respective bids/offers. The NMF communicates availability and contract costs to the WSC. The NMF provides visibility of the actions (e.g., flexibility dispatch) by industry actors so that these actions and their impact on the network is considered when making operational decisions. It's worth highlighting that, unlike traditional active network management schemes (ANM), the NMF does not have any direct communication to the physical assets owned by the industry actors.

The WSC calculates the network flexibility requirements (i.e., needs analysis) based on the constraints identified by the PSA tool and the Operational Forecasting engine. The WSC outputs the flexibility requirement and respective time window. The WSC communicates the flexibility requirement to the NMF, which then advertises with industry actors. The NMF sends a list of potential offers, for the WSC to perform a total contract valuation to select the least cost option that resolves the constraints according to the PSA model.

The network model and PSA are used at several stages during the flexibility trials, with different functionalities required from the PSA tool depending on the timeframe and output required.

It's worth noting that an updated view of the network connectivity and nodal forecasts of demand and generation are used to refine the flexibility requirement estimation as the market moves closer to the time of dispatch.

Separately, the PSA is also used to approve the Peer-to-Peer capacity trades, also called DSO-enabled services. While this functionality was not yet fully trialed in TP1, one of the objectives for the subsequent trial periods is to use the PSA model to evaluate and approve/reject P2P trades. The power flow will issue a pass/approval of the trade if no constraints are detected as a result of the proposed P2P trade or issue a fail/rejection of the trade if any constraints are found. Based on the agreed P2P trade, the PSA model will update the generation/demand forecast for the particular flexibility asset, according to the duration stated in the contract. This will be done using a simple ratio of the new and the original capacities.

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- **Power Flow (PF-PSA)** which determines *“For a given set of demand/generation injections to the nodes on the network, what will be the flows on the lines/cables/transformers, and the resultant voltages on the nodes?”*
 - **Optimal Power Flow (OPF-PSA)** which assesses *“If the network branch elements have a certain maximum thermal current-carrying capacity and if nodal voltages need to be kept within certain min/max bounds, then what should be the nodal injections (including available flexibility source contracting/dispatch actions) to ensure that all such constraints are satisfied?”*

1.2 Trial Areas of Interest in the Oxfordshire Area

The report “TRANSITION Site Selection Methodology” [2] outlines the main factors that make Oxfordshire the optimal location for the TRANSITION flexibility trials. Most of the Oxfordshire region is within the SSEN Southern Electricity Power Distribution (SEPD) license area, where SSEN owns and maintains the distribution network. A small area on the east and on the north are outside of the SEPD area and are instead within Western Power Distribution’s license area, thus these are out of scope. Figure 5 illustrates this more clearly.



Figure 5. Oxfordshire area (in blue) within the SEPD (in white) license area

Specific areas within Oxfordshire were selected to carry out the flexibility trials, ensuring equality between rural and urban communities, varied demographics and mix of low-carbon technologies (LCTs). An important consideration was the collaboration with the partners from the LEO project. Part of the identification process involved analysis of the assets and the viability of these assets to participate in the flexibility trials. Detailed information of this selection process can be found in [3].

Figure 6 shows the Oxfordshire area part of the trials, the ESA covered by the BSPs, the Primaries within these BSPs and the secondary substations that have monitoring equipment. The flexibility assets are also shown.

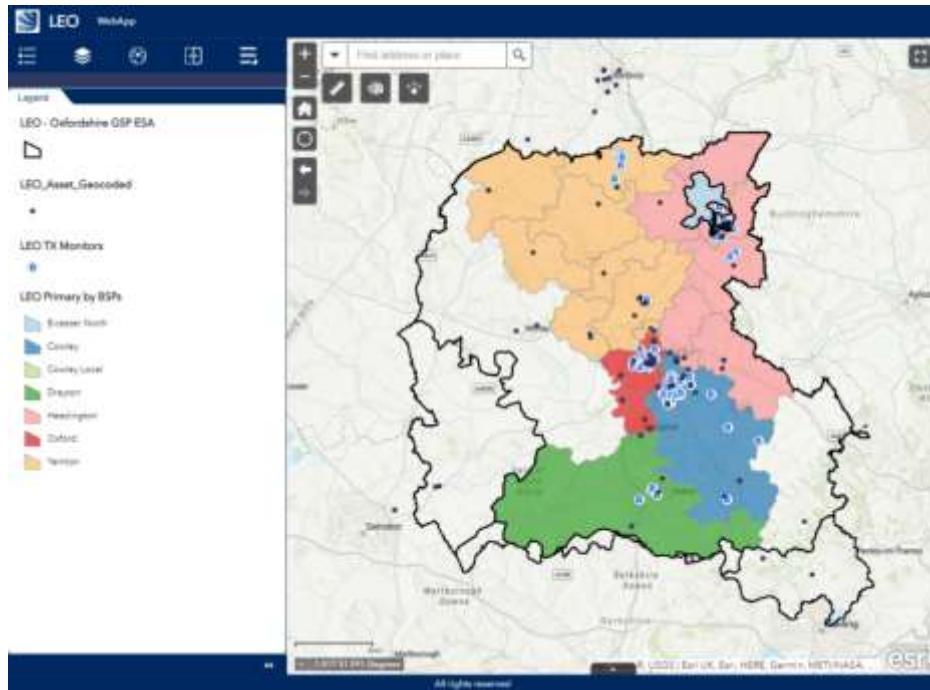


Figure 6. Interactive map developed for the LEO/TRANSITION trials showing the secondary substations with LV monitors within the BSPs of interest

The Primary substations selected for the TRANSITION trials are listed below and their Electricity Supply Areas (ESAs) are illustrated in Figure 7:

1. Arccott
2. Berinsfield
3. Bicester
4. Bicester North
5. Deddington
6. Eynsham
7. Kennington
8. Milton
9. Oxford
10. Rose Hill
11. University Parks
12. Wallingford
13. Yarnton

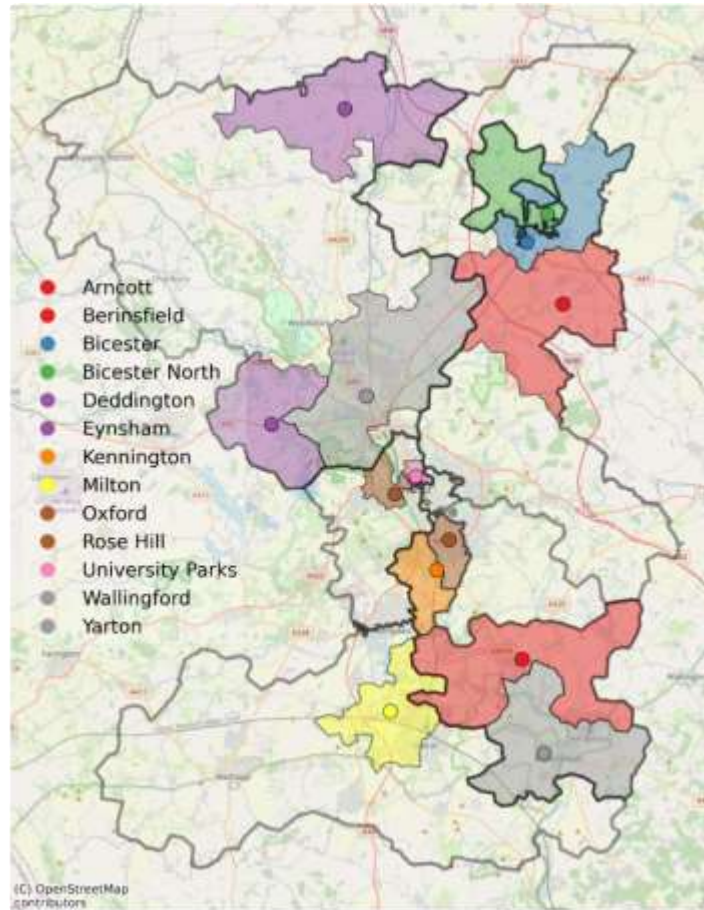


Figure 7. Primaries of interest. Shapes indicate the ESA; circles indicate location of the substation.

The Network hierarchy is described in Table 1. Each Grid Supply Point (GSP) feeds several Bulk Supply Points (BSPs) and these in turn feed several Primary substations. Each Primary substation supplies several 11kV feeders, where secondary substations are connected to.

Table 1. TRANSITION network area of interest and hierarchy

GSP	BSP	Primary	
East Claydon	Bicester North	Bicester North	
		Bicester	
Cowley	Cowley Local	Kennington	
		Rose Hill	
		Wallingford	
		Berinsfield	
	Drayton	Milton	
	Headington	Arccott	
	Oxford	Oxford	
		University Parks	
	Witney/Yarnton	Witney/Yarnton	Yarnton
			Eynsham
Deddington			

It's worth noting that the 13 Primary substations that are part of the trial area in Oxfordshire do not necessarily cover the entire ESA of the BSPs. There are other primaries supplied by those 6 BSP that are not part of the scope of the TRANSITION trials. However, these "out-of-scope" Primaries do influence the overall BSP load level and the forecast. In total there are ~ 40+ Primary substations supplied by the 6 BSPs (Witney and Yarnton are considered together, as a single BSP, due to meshing at 33kV, details on this are given in Section 4.1.1).

A high-level diagram is shown in Figure 8 to illustrate this, while providing a view of the network hierarchy and connectivity. The out-of-scope Primaries will be modelled only as a transformer with an aggregated load connected to the 11kV busbar. The 13 Primaries in scope will have detailed models of the 11kV feeders, including all the secondary substations and transformers (11/0.4kV) connected to each of the feeders.

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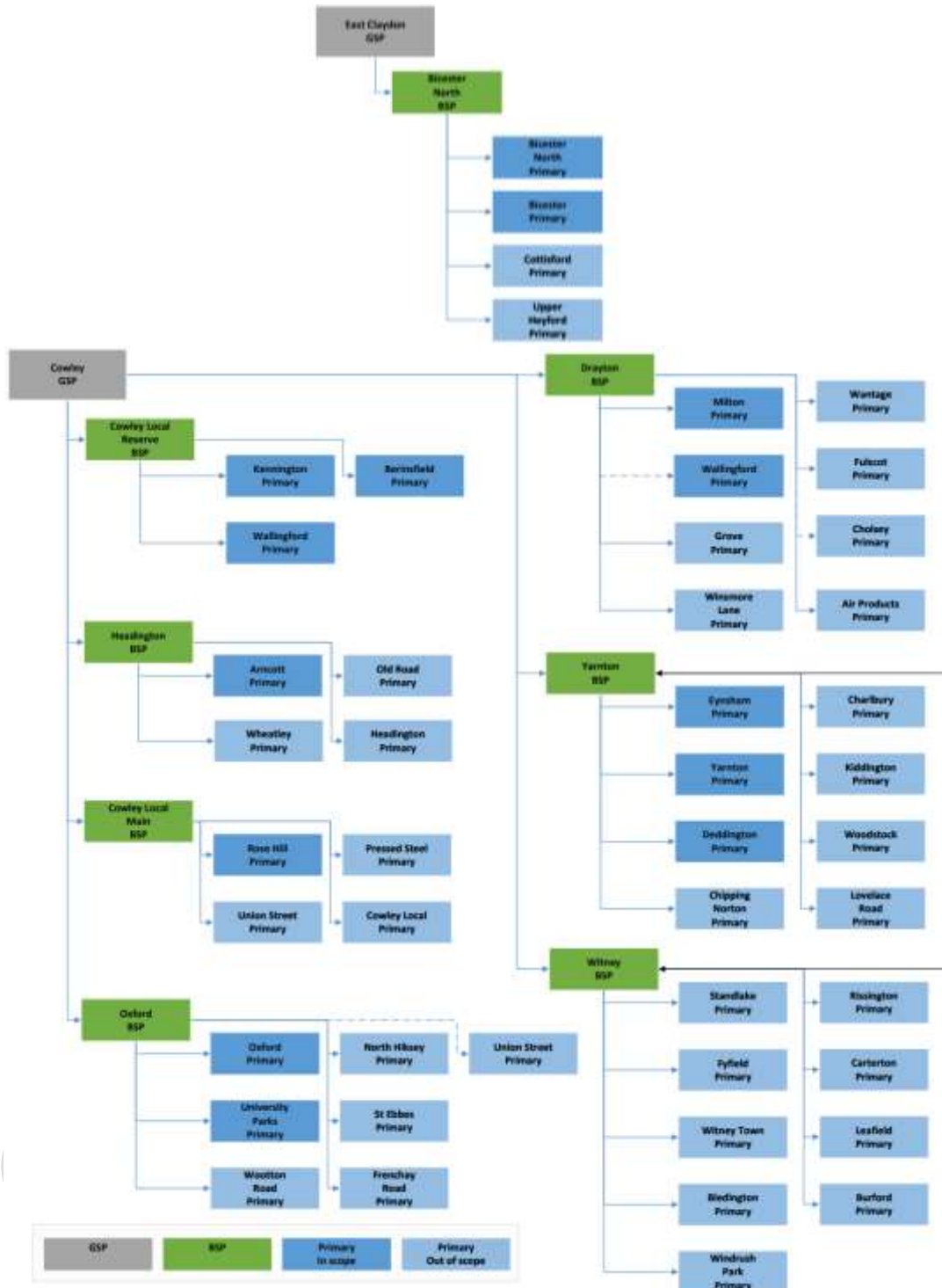
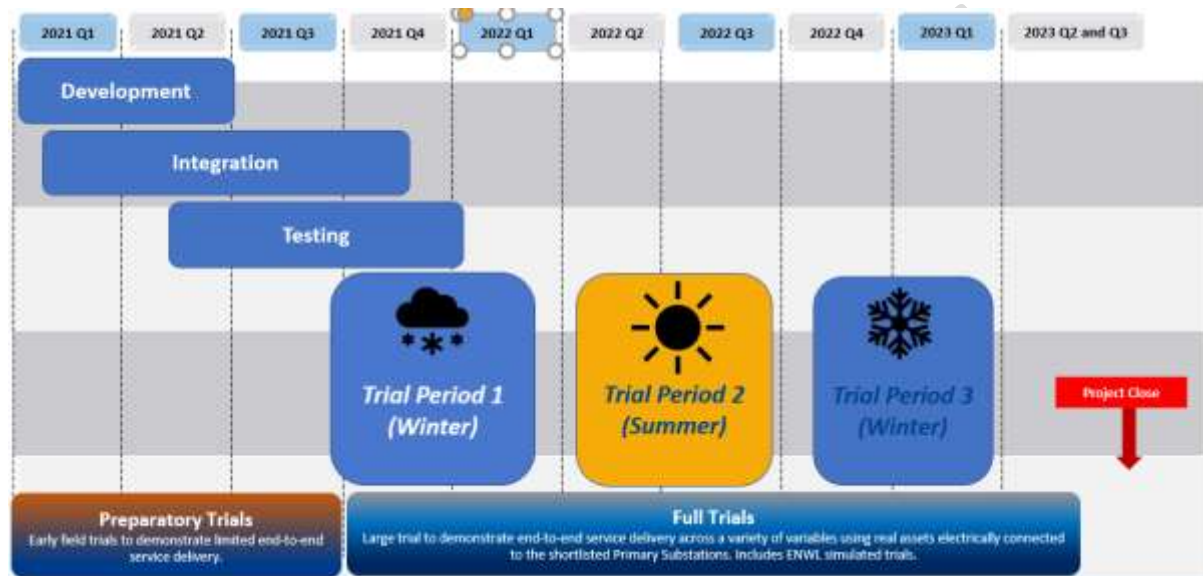


Figure 8. GSPs, BSPs and Primary Substations high-level connectivity diagram of the TRANSITION network model

1.3 Overview of Trial Periods 1, 2 and 3

As mentioned above, the projects will together run with three consecutive Trial Periods. The timeline for these is outlined below. The PSA network model will be evolved throughout the work programme to ensure that it is fit for purpose for the tests contained within each. For example, winter and summer trial periods may require alternative network element thermal ratings, and different voltage control strategies to be applied to the model. Furthermore, as different flexibility services may be tested across the time periods, then different technical criteria may apply in each case (e.g., Sustain service may look at a base case intact topology, whereas Dynamic service may be looking at scenarios with abnormal running arrangements and topology changes).



1.4 Overview of the teams involved

The development of the PSA models and tools used in the TRANSITION trials has been a complex and lengthy process, with the involvement of many partners. Several SSEN internal subject matter experts have been involved in providing advice and input data for the development of the model. We have also benefitted from the advice of external consultants and partners, e.g., RINA Consultants who have helped with specialist knowledge and extra resource, Open Grid systems (OGS) who have provided specialist knowledge and support on all matters related to Common Information Model (CIM) data processing. Finally, though the main offline PSA model development tool in use in the project has been DigSILENT PowerFactory, the operational systems used to run the PSA model in the trials has been provided by OpusOne (developers of the Whole System Coordinator and the Neutral Market Facilitator). Some summary advice on those organisations follows here⁴.

⁴ RINA is a global corporation that provides engineering and consultancy services, as well as testing, inspection, and certification. RINA supported the TRANSITION project in developing integrated PSA models across several levels of the network, from 132kV to secondary substation, using different network models from SSEN from various sources such as PSS®E and PSS-SINCAL into one single model capable of being reflective of the operational network.

Open Grid Systems is a software company that provides model-driven electrical network data management, analysis, and visualisation solutions. Open Grid Systems has supported TRANSITION through a combination of software and services to transform, integrate, manage, and analyse multiple data sets into a single, unified network model defined by open IEC standards. This unified model provides the foundation for the simulation and analysis work undertaken by the other project partners, as well as providing a foundation for SSEN's ongoing network-focused Open Data initiatives.

1.5 Overview and Structure of the Report

The aim of this report is to provide an overview of the development process of the PSA model for the TRANSITION project, the PSA tools used and to describe the use cases in the context of the flexibility market trials. The report is divided into sections as follows:

- **Section 2** introduces the motivation for a PSA model in the TRANSITION project and gives an overview of the parts of the network targeted, the different PSA tools used and the need for the CIM format to facilitate interoperability.
- **Section 3** describes the development process of the network model in more detail and describes some of the challenges faced when building models from GIS data.
- **Section 4** describes the different data requirements for building a network model, it focuses on the differences between a planning and an operational model and on the data requirements to make the model suitable for use during the TRANSITION flexibility market trials.
- **Section 0** describes the different validation stages required and presents some of the challenges experienced when transferring models between different PSA tools.
- **Section 5** provides more detail on the use case of the PSA model in TRANSITION, including the different stages in the flexibility procurement process and the timeframes. It also provides some high-level results when testing the PSA model.
- **Section 6** summarises the key learnings and provides conclusions.
- **Section 7** discusses the assumptions made, and the areas that will be considered in future work.

2 PSA Model Requirements for TRANSITION

As described in Section 1.1.2, a PSA model is needed to estimate the flexibility requirements in each network and to select the assets that can provide this flexibility to alleviate network constraints. This section gives an overview of the use case in TRANSITION.

2.1 Modelling a combined hierarchy of EHV/HV/LV

One of the factors investigated in TRANSITION is the procurement and dispatch of flexibility, which can come from customers connected to different parts of the network, to resolve constraints in the

Opus One Solutions from GE Digital is enabling the digital utility with our advanced distribution energy management platform, GridOS®. Opus One has supported TRANSITION by developing the Neutral Market Facilitator and Whole Systems Coordinator platforms necessary to support flexibility markets at scale.

network. For example, an aggregation of customers at HV or LV can potentially resolve a constraint in the EHV part of the network.

Because of this, an integrated 132/33/11kV network model was developed for the TRANSITION trials. In other words, the model represents the 132kV GSP feed as the slack bus (i.e., external network) and includes the 132kV lines and the 132/33kV BSP transformers. Also, it will model the 33kV network, any customer connected directly to this network and all the 33/11kV Primary substations in Table 1.

The network model will also include detailed models of the 11kV feeders (for the 13 selected primary substations in Table 1), comprising all the secondary substations and transformers (11/0.4kV) connected to each feeder. The LV feeders will be omitted initially, to keep the level of detail (and computational expense) to a reasonable level, however this will be expanded in the future (see Section 7). The demand from the customers connected to the LV network will be represented as an equivalent total demand at the LV busbar of the secondary transformers.

It is expected that majority of the flexibility assets will be connected to the 11kV network or the LV network. Hence, those connected at 11kV will be modelled accurately, whereas those connected to the LV network will be aggregated to the LV busbars of the secondary substations.

Figure 9 provides an illustration of the network hierarchy, as a simplified single line diagram (SLD).

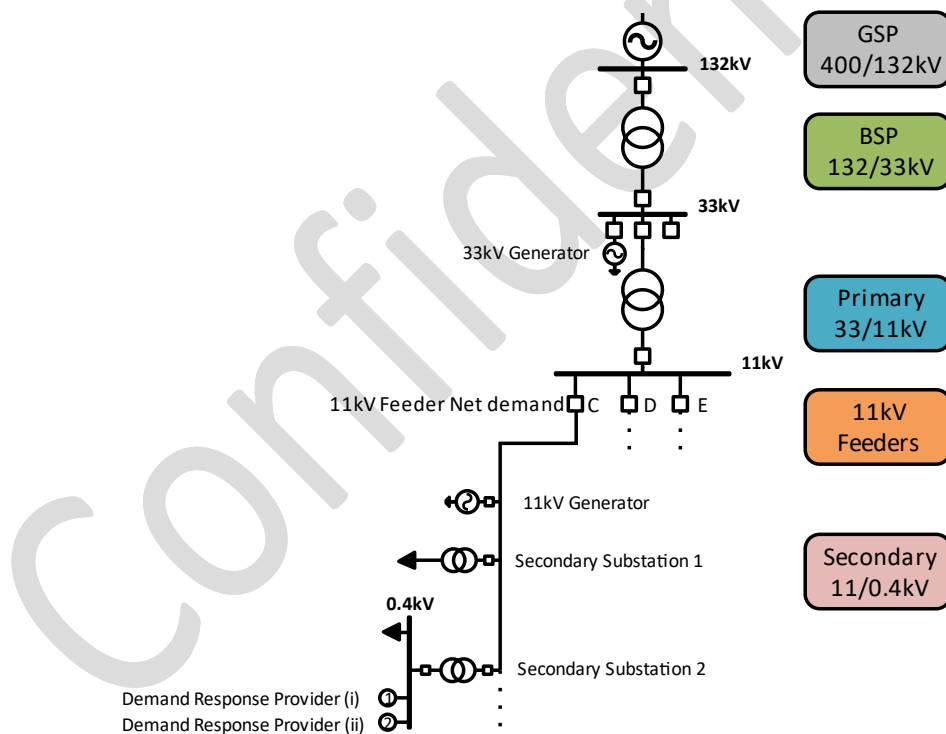


Figure 9. Distribution network hierarchy as a simplified single line diagram (132/33/11kV)

2.2 Developing Operational Network Models

Because the network model developed will be used to estimate the flexibility requirements, procure this flexibility, and dispatch the respective assets, in time periods close to real-time, the PSA model developed and used needs to have certain operational-timeframe characteristics.

Unlike traditional network models used by a System Planning team to plan the network and to prioritise investment decisions, an operational model used for flexibility market decisions needs to provide a view of the state of the network on a much shorter time horizon, closer to real-time. In the case of TRANSITION, the time resolution is half-hourly or one hour depending on the service, and typically looks at analysis from time horizons stretching from very close to real-time out to within a 7-10 day look ahead.

This operational network model is made possible by the interaction of multiple systems and tools, as was described in Figure 4. A master version of the network model is developed offline in DigSILENT PowerFactory by taking as input the System and Network planning models and is then exported into GridOS (IDP) using the Common Information Model (CIM) standard.

To drive the network model and maintain an up-to-date state of the power flows in the network, forecasts of demand and generation are provided to the network model every 30 min via an API. These inputs are then used to solve power flows or optimal power flows, respectively. The OPF gives as output a forecast of the state of the network and highlights any potential constraints. If any constraints are identified, the WSC then calculates the flexibility requirements to alleviate such constraints.

An operational model also requires a constant data stream that informs the state of the circuit breakers and switches to maintain the true connectivity. Real-time data from SSEN's SCADA/Power-On systems are available as input for this purpose, though are not yet fully integrated to the system. This integration to the model for truly real time PSA model connectivity will be delivered in the later Trial Periods.

While the initial data sets used to build the TRANSITION network model come from a System Planning perspective, the additional inputs described above make the model a fully operational model, which can inform the network requirements on a close to real-time timeframe, whilst considering changes in the network connectivity and fluctuations in generation and demand.

2.3 PSA Modelling Tools

Multiple modelling tools were used to develop the operational network model used by the WSC during the TRANSITION trials. This is because traditionally different parts of the network are modelled in different tools, depending on the assumptions and modelling philosophies (e.g., PSS[®]E is used by the System Planning team, whereas the Network Planning team uses PSS SINICAL).

A power system analysis (PSA) tool is required to build a model of the network and to perform power flow calculations. A power flow calculation provides a snapshot of the steady-state operation of a given network model. It takes as input a model of the network, a set of load and generation setpoints and it outputs the voltage, currents, and power flows throughout the network, as well as the setpoints for control devices (e.g., tap changers). The power flow is a non-linear problem and thus it requires an iterative method. The most common method used in most PSA tools is the Newton-Raphson [4].

An Optimal Power Flow (OPF) differentiates from a power flow in which, it calculates the optimal voltage, current and power flows, as well as control devices setpoints that meet an objective function whilst respecting the network constraints (i.e., operational limits). The cost-function could

be the cost of running the generators or could reflect some desirable network operating feature (e.g., minimising power losses). For the TRANSITION trials, the cost function can reflect the total cost of utilising a certain flexibility resource to alleviate a network constraint, capturing elements of both the availability and utilisation costs of such services.

DigSILENT PowerFactory will be used by the TRANSITION project as the main model development tool, whereby an integrated 132/33/11kV base model will be created offline, and then uploaded to Opus One so that the model can be imported into the WSC to inform the real-time operational systems applied in the flexibility market trials. The DigSILENT PowerFactory model will combine the BAU network model from PSS®E and detailed models for the 11kV feeders reconstructed from SSEN GIS Electric Office.

2.3.1 Overview of PSS®E

PSS®E is a PSA tool from Siemens that can perform power flow calculations, as well as fault analysis and dynamic simulations. PSS®E is used by several teams within SSEN to develop and maintain the 132/33kV network model. This includes updating the network normal running arrangement, as well as including any new connections, such as generators. PSS®E was designed mainly as a tool to model transmission and sub-transmission networks, thus the power flow algorithms assume of a balanced network. PSS®E stores network models as data tables, which can then be used to build the single line diagram (SLD) of the network.

The most up to date 132/33kV network model was exported from PSS®E and imported into PowerFactory to form the base of the TRANSITION network model.

2.3.2 Overview of DigSILENT PowerFactory

DigSILENT PowerFactory was used by the TRANSITION project as the main model development tool, whereby an integrated 132/33/11kV base model was created and provided to Opus One. The DigSILENT PowerFactory model integrated the BAU EHV model from PSS®E and models for the 11kV feeders reconstructed from SSEN GIS systems. PowerFactory has significant modelling capability to suit this integrated EHV and HV modelling requirements of TRANSITION/LEO, capturing technical issues across multiple traditional separable voltage levels [5].

The main PowerFactory functions used in the TRANSITION project include Load Flow Analysis, Power Equipment Models, Network Model Management, Network Reduction, Python API scripting and CGMES CIM import/export tools.

2.3.3 Overview of GridOS

The overall GridOS platform from OpusOne will be used by the TRANSITION project as the Whole System Coordinator (WSC), Neutral Market Facilitator (NMF), and online/operational Power Systems Analysis (PSA) tools. GridOS' sub-component Transactive Energy tool will be deployed for the WSC and NMF, whereas GridOS' sub-component Optimization Engine tool will provide analytical support for the PSA. GridOS's subcomponent Integrated Distribution Planning (IDP) tool provides an interface for SSEN to import and edit the network model within GridOS.

Figure 10 below shows a simplified layout of how the different GridOS applications are used within the project.

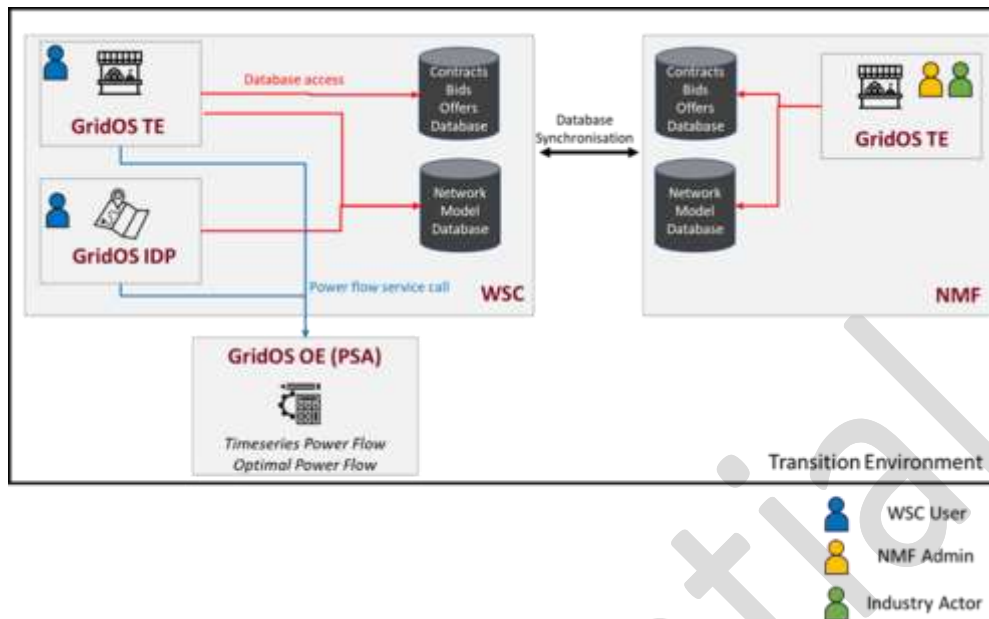


Figure 10. Overview of Opus One WSC, NMF and PSA architecture

2.3.4 Overview of Electric Office

Electric Office (EO) is SSEN's Geographical Information System (GIS), which stores the network asset's physical location and specifications (e.g., cable types and lengths). Electric Office provides a view of the electricity network from the 132kV up to the LV. It also includes information on the customers location and their network connectivity. An essential feature of Electric Office is the ability to trace the path of the power flows, this can be from a customer endpoint towards the substation that supplies that customer (upstream trace) or from a substation to the customers (downstream trace). The information collected as part of a trace can be extracted from Electric

Office in XML/CIM format and this can form the basis of a network model suitable for power flow studies.



Figure 11. Illustration of a Primary substation in Electric Office

2.3.5 Overview of PowerOn

PowerOn is a specialised operational software application, also known as Distribution Management System (DMS), which is designed to be used for the monitoring and management of an electricity distribution network. PowerOn displays the real-time state of the system in a network diagram, and it stores the true connectivity of the network. The NOP are indicated by black arrows pointing to the respective circuit breaker.

For historical reasons, PowerOn only includes information on the network at 132/33/11kV. The LV network downstream from the secondary substations is not represented in PowerOn. PowerOn receives SCADA data from remote terminal units (RTUs) and displays this to the engineers in SSEN. This data allows the engineers to view the current running arrangement, assess whether there are any constraints on the system (e.g., voltage exceeding the statutory limits) and to see whether there are any maintenance/upgrade jobs scheduled.

2.3.6 Python scripting

Because of the sheer amount of data needed to build and maintain a 132/33/11kV network model, scripting was seen as a requirement to parse and process the data, setup the network model, as well as to automate the power flow studies and analyse the results.

Additionally, PowerFactory has an API capability that allows the user to drive the application using Python scripts. This API offers direct access to the PowerFactory data model, the calculations, and their respective results (e.g., power flow). The API is designed as an automation interface (e.g., to automate power flow studies with different setpoints) [5].

The API consists of 5 classes [5]:

- API entry point
- Application (running instance of PowerFactory)
- OutputWindow (displays information to the user)
- DataObject (encapsulates PowerFactory objects)
- ExitError (Throws exceptions when PowerFactory cannot start)
- Value (data value that can be an input for the data model or an output of a calculation)

A suite of Python scripts was developed to support the development and validation of the network model and to automate power flow studies. For example, a script was developed to change the active and reactive power setpoints of the loads and generators to simulate a particular scenario (e.g., winter peak demand).

2.3.7 Common Information Model as an interoperability tool

Because of the several PSA tools used to develop sub-elements of the various stages of the overall integrated model, there is a need for a common language that ensures models can be imported and exported out of the different PSA tools at the different stages of the development process. CIM interoperability was a key area of focus of the TRANSITION project, so that (i) models can be passed between different systems and (ii) the PSA results of those models were consistent when evaluated therein.

The data model defined by the IEC 61968-11 and IEC 61970-301 standards, typically referred to as the Common Information Model (CIM), was identified in the TRANSITION project as serving the purpose of enabling interoperability between different PSA tools.

These standards are widely used throughout the world for exchanging and storing power system data in an open structure and format. ENTSO-E, the European Network of Transmission System Operators for Electricity, uses CIM as the core of their Common Grid Model Exchange Standard (CGMES), used by 42 transmission network operators (TSOs) across Europe to exchange electrical network models. It is also used by DSOs and TSOs world-wide as the foundation of their Enterprise Information Model and for system integration. Moreover, Ofgem has recently identified CGMES 3.0.0 as the basis for a CIM version of the Long-Term Development Statement [6].

Additionally, CIM was chosen by the TRANSITION team because of three fundamental reasons inherent to the project:

- SSEN's GIS database (Electric Office) can export data in CIM format, and these exports were identified as a potential source to build the 11kV network models
- PowerFactory can import and export network models in CIM format
- The PSA tool used in the WSC, GridOS, can import and export network models in CIM format

Although there are many versions and profiles of CIM, the current target version of CIM for TRANSITION is CIM v16, as this aligns with the CGMES v2.4.15 standard, and currently has the widest industry support. The CIM data used for TRANSITION will be for a balanced, three-phase system, which aligns closely with the CGMES v2.4.15 standard. The CIM has a standard for distribution, IEC 61968-13 (Common Distribution Power System Model), but the last published version of this standard from 2011 is based on an earlier version of the CIM and the differences are more applicable to unbalanced, low voltage modelling which is typical in North America. Using CIM v16 will also ensure that any CIM processes and outputs used in TRANSITION will be able to move from CIM v16/CGMES v2.4.15 to the most recent version of CIM v100/CGMES v3.0.0 with minimal changes and without any loss of data.

2.3.8 Overview of Cimphony

Open Grid's Cimphony Concert is a scalable data management platform that combines a standards-based persistent data management platform with an integrated real-time database. This system stores multiple, interconnected catalogues of data in a standard structure, allowing multiple modules and external applications to connect, extract and update data. The Cimphony data repository uses the IEC Common Information Model (CIM) as the base information model.

Open Grid's Cimphony frameworks provide a means of directly importing a CIM network model into its Network Model Management (NMM) environment. Cimphony supports CIM v10-16, including: all extensions for ENTSO-E CGMES v2.4.15; extensions covering DERMS systems; draft IEC standards; and support for the IEC 61970-552 CIM RDF XML format. Currently, Cimphony supports the import of data from several power systems analysis applications including PSS/E, PSLF, CYMDIST, Synergi and DigSILENT PowerFactory through its DGS format. This includes conversion of these data formats into CIM for both distribution and transmission systems.

Once the data is converted into CIM it can then be validated using Cimphony's built-in validation tools. This includes:

- Checking the data is valid XML
- Checking the data conforms to the serialisation format rules (e.g., IEC 61970-552 CIM RDF XML) including validating XML namespaces
- Checking the data against the meta-model class structure and that classes, attributes and references are valid (e.g., ensuring any classes or attributes exist in the declared version of CIM or any customer defined extensions)
- Executing detailed validation rules defined in the Object Constraint Language (OCL) including standard rule sets based on IEC and ENTSO-E standards

Additionally, Cimphony can process, analyse, and convert all, or parts, of the integrated model into different versions of CIM or other power system formats. This includes:

- Inter-CIM version conversion (e.g., from CIM v15 to CIM 16)
- The ability to split integrated models into multiple data sets to cover the partitioning of the network into multiple parts including logical network groupings (e.g., by geographical area or feeder)
- Splitting the data by type into standardised CIM profile-defined datasets for equipment, starting conditions, state variables, topology, diagrams, geographical data etc.

As part of TRANSITION, Open Grid has carried out several tasks including the import, processing, conversion, and validation of CIM models from Electric Office. This is described in more detail in Section 3.1.

3 Model Development Process

As introduced above, traditionally in SSEN the 132/33kV network is modelled separately from the 11kV network and furthermore that is analysed separately again from the LV network. These last two HV and LV levels of the network are often modelled in detail at only ad hoc junctures, e.g., when assessing a new connection request (i.e., a customer wishing to connect new demand or generation). For this reason, the process to build the integrated (132/33/11kV) network model for the TRANSITION project required two parallel sub-process, later joined together, to consider these two datasets.

The first step was to export the PSS®E SEPD model for the 132kV and 33kV network and import it into PowerFactory. For the 11kV network, individual CIM v15 files were taken from the output of the Connectivity+ project and converted into CIM v16. Open Grid Systems (OGS) supported the conversion process and included several processing and validation steps to ensure the files were compatible with DigSILENT PowerFactory.

Once the PSS®E model and the 11kV feeders were imported into PowerFactory, several steps were needed to carve out the 6 BSPs of interest from the 132/33kV SEPD network model, create individual models from each BSP and bundle the 11kV feeders into their respective Primaries. RINA established a robust process to ensure the final network model contains all the required assets and to make sure the connectivity represented the normal running arrangement of the network.

Once a final network model was developed and the power flow converged in PowerFactory, the model was then exported in CIM format and passed to Opus One. The model was then imported into the WSC and became the operational model, which can take as input the forecasts from the operational forecasting engine developed by Sia Partners. A final validation of the results obtained in the WSC and in PowerFactory was carried out to make sure the results align between the two PSA tools.

Figure 12 provides an overview of the process that was followed to build the integrated network model for the TRANSITION project, which is used in the WSC for trials. The following sections give a more in-depth description of each of the individual development stages.

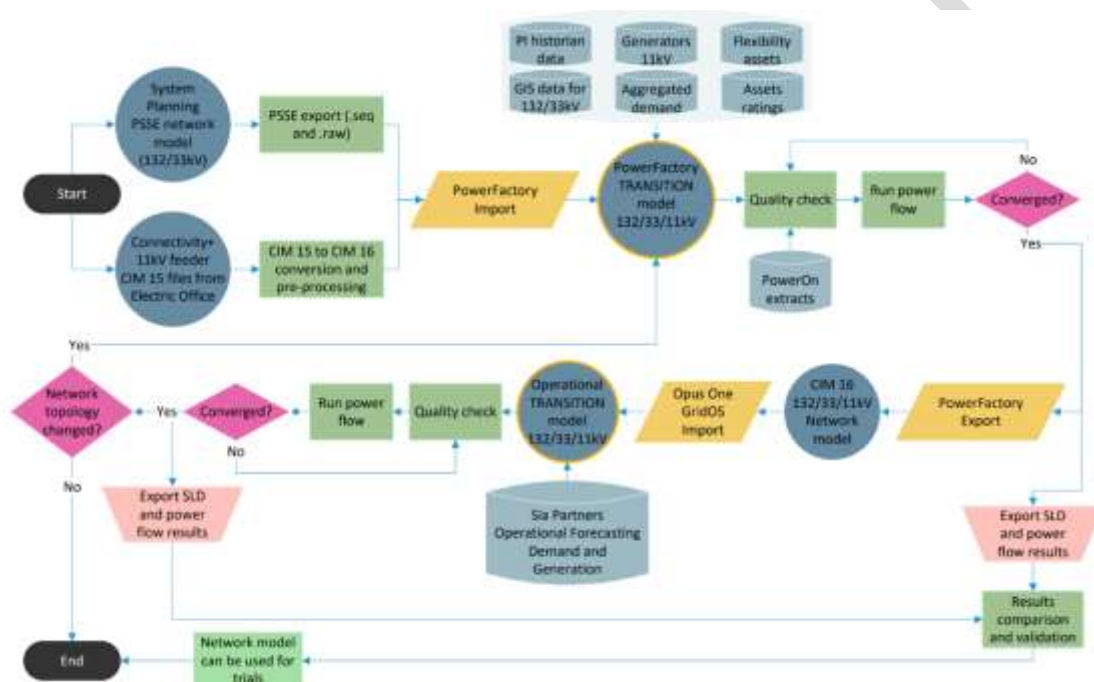


Figure 12. Overview of the TRANSITION network development process

3.1 Building 11kV Network Models from GIS Data

Unlike the 132kV and 33kV network, there are no central network models of the 11kV network. However, the connectivity and asset data for this part of the network is stored and maintained within the Geographical Information System (GIS) at SSEN. The GIS, Electric Office (EO), is capable of exporting data in CIM, and so these exports were identified as a suitable data source to build the 11kV network models for use in the TRANSITION project. This avoids having to build the 11kV network manually.

Additionally, another innovation project, Connectivity+, was underway concurrently within SSEN, which main goals were to identify and correct data quality issues within the GIS data to improve the CIM exports. This aligned closely with the requirements from TRANSITION and thus the outputs of Connectivity+ were used as the source data for the 11kV network model.

3.1.1 Processing GIS data

As mentioned in section 2.3.7, although the CIM format is a standard language, there are different versions and profiles, and this can create some compatibility problems when importing/exporting. For this reason, SSEN and Opus One have agreed that the network model will be developed in PowerFactory and exported using version 16 of the CIM standard, using version 2.4.15 of the ENTSO-E Common Grid Model Exchange Specification (CGMES).

The data exported by Electric Office is in CIM v15 which dates from 2010. Hence, several pre-processing and conversion stages were needed to convert the CIM exports from Electric Office into CIM v16, which were compatible with both PowerFactory and the WSC, and to ensure the CIM files represented network models suitable for power flow analysis. This process was undertaken by Open Grid Systems using a suite of software applications for CIM.

3.1.2 Challenges and issues when processing GIS data

The first step in using the Electric Office exports was to import them into the OGS Cimphony suite of applications to identify any errors or warnings with the source data. This step identified several issues that had to be corrected. For example, some classes and relationships in the data were incorrectly marked as being IEC standard and so produced errors. Another step was to translate the Electric Office representation to a CIM compatible representation and to remove any duplicated items.

Following this, a more detailed examination of the data was undertaken both manually and using automated processing algorithms. This identified several problems that had to be corrected to allow the data to work with other CIM-compatible applications (e.g., PowerFactory). For instance, the Electric Office data contains the overhead lines and cables with an associated Asset and Cable or Overhead Wire Information object that defines the type of cable. However, the CIM objects do not have any impedance, susceptance, or ratings data on them which means they lack sufficient data to support network analysis applications such as power flow.

A step was added that matched the cable/line types in the CIM with the line parameter datasets, which were provided by SSEN as an Access database, and used to calculate the impedance. Where the lines had length values populated from GIS, these were used, where the length was missing, it was calculated using the geographical data. Operational Limits were also added to each line/cable with the Current Limit in Amperes taken from the Access database.

Finally, the files lacked any geographical containment which is a requirement for IEC and CGMES network exchange standards. Hence, some additional steps were included to merge the separate geographical data file from Electric Office, which comes as a Geographical Markup Language (GML) file, into the CIM file (XML) to create a single, integrated CIM dataset.

3.1.3 CIM version transfer

Although the CIM format is a standard language, there are several different versions and profiles, with initial work on the standard undertaken by the Electrical Power Research Institute (EPRI) in the 1990s. This can create some compatibility problems when importing/exporting between different tools if the version used is different.

For instance, as mentioned in Section 3.1.1, the data exported by Electric Office is in CIM v15, and with the exception of some minor non-standard customisations within the output from Electric Office, the file conforms with the IEC data model standard, and the accompanying serialisation format (IEC 61970-552 CIM RDF XML).

However, as discussed in Section 2.3.7, CIM v16 is more widely supported as it forms the foundation of the ENTSO-E CGMES v2.4.15 standard used for transmission model. Both PowerFactory and the PSA used in the WSC (GridOS) have import and export capabilities in CIM format and they use v16.

For this reason, SSEN and Opus One have agreed that the network model would be developed in PowerFactory and exported using version 16 of the CIM standard, using version 2.4.15 of the Common Grid Model Exchange Specification (CGMES).

A conversion from CIM v15 to CIM v16 was therefore required to enable the data to be used with the other CIM conversions implemented for TRANSITION, and to align with the support within the software from other vendors including DlgSILENT PowerFactory.

The conversion from CIM v15 to CIM v16 was undertaken using OGS off-the-shelf CIM conversion functionality within its Cimphony software. This converted the data into an IEC CIM v16 structure, then serialised it in RDF XML.

When the output was intended for PowerFactory or other software with explicit CGMES v2.4.15 import requirements, the data was further separated into the individual CIM XML files containing:

- Core Equipment and Connectivity (e.g., ROSH_E1L5_EQ_CO.xml)
- Geographical Location (e.g., ROSH_E1L5_GL.xml)
- Starting Condition (Steady State Hypothesis) (e.g., ROSH_E1L5_SSH.xml)
- Solution (State Variables) (e.g., ROSH_E1L5_SV.xml)
- Computed Topology (e.g., ROSH_E1L5_TP.xml)

These files included IEC standard header data and then encapsulated in a single ZIP file.

3.2 Building an Integrated Network Model 132/33/11kV

Once the 11kV network files were converted into a CIM format compatible with DlgSILENT PowerFactory, RINA did the main development and integration process in this tool. This process consisted of importing the System Planning network model and merging it with the 11kV network files to form an integrated network model (132/33/11kV). An overview of the process followed by RINA is given in the following subsections and is summarised in Figure 13.

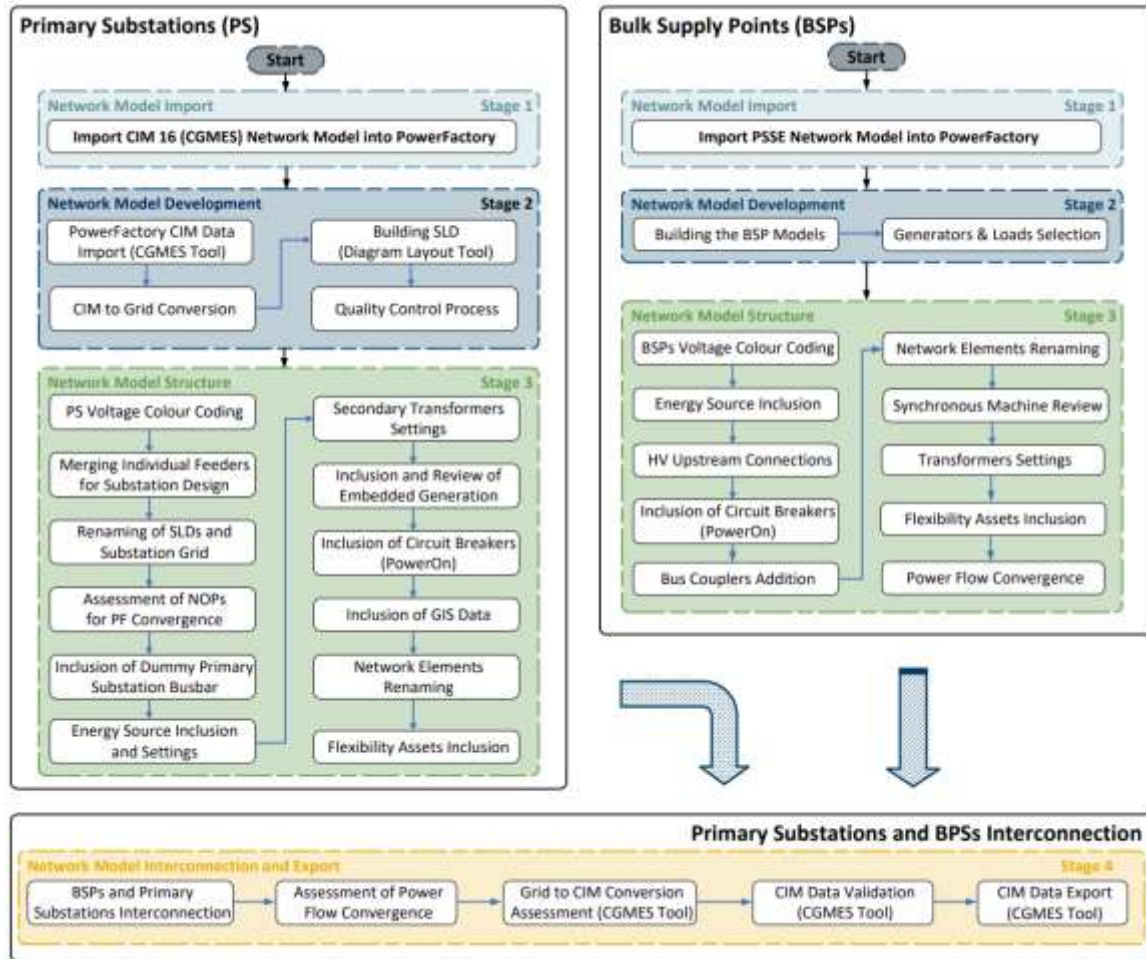


Figure 13. Process flowchart for the development of the TRANSITION network model

3.2.1 Stage 1: Network model import

This first step consisted of importing both the PSS®E and the CIM v16 files into PowerFactory. The PSS®E import contains all the network area within SEPD, whereas each of the 11kV feeders comes as a separate CIM v16 file.

3.2.2 Stage 2: Network model development

The PSS®E model imported in PowerFactory included all the GSPs and associated BSPs in the SEPD license area, hence an additional step was required to carve out the area of interest. The BSPs of interest are separated into individual PowerFactory models, following the connectivity diagram in Figure 8. This is done to keep a reasonable number of network components and nodes once the 11kV network is incorporated. All the generators and loads connected downstream from each of the BSPs are included in the individual BSP models.

3.2.3 Stage 3: Network model structure

Once the BSP were separated into individual models, a slack bus (referred to as energy source in PowerFactory) was included in each of them. This slack bus represented the respective GSP busbar (i.e., Cowley or East Claydon). This step also involved verifying the transformer settings and associated tap changers, as the representation is different in PSS®E compared to PowerFactory. Additionally, the naming convention used in PowerOn was adopted for all network assets (including loads and generators) to facilitate validation. Finally, the 132kV and 33kV running arrangement, as well as the circuit breakers, were validated according to the latest view from the operational model in PowerOn.

During this step, the 11kV feeders were merged forming their respective Primary substation. Two separate steps are required to merge the databases together and to connect them electrically. A key step required to connect the feeders together is to identify the normally open points (NOPs), which indicate where each of the feeders terminate. This was done using connectivity extracts from PowerOn. Finally, the parameters of the secondary transformers were validated according to SSEN internal equipment database Maximo.

3.2.4 Stage 4: Network model export

This step merges together the Primaries with their respective 11kV feeders with the BSP models to produce a final 132/33/11kV network model. Each of the 11kV feeders is represented as a separate SLD to facilitate visualisation, whereas the main SLD contains the BSP and Primaries.

A series of power flows are carried out, enabling the Primaries incrementally, to validate the network models converge successfully. Once this is done, the complete BSP model is converted to CIM format and exported for use in the WSC.

3.3 Naming Conventions

Because of the large number of network components in the network models, and because of the format requirements of the CIM standard, naming conventions needs to be adopted to facilitate validation of connectivity and cross-reference to other databases.

3.3.1 Object names in CIM

The ENTSO-E CGMES standard sets a limitation on the number of characters for object names. There are only 32 characters available in the CIM file format attributed to a network component or flexibility asset, hence this limit on the maximum number of characters.

To ensure the names are unique, SSEN suggested to include the Grid Reference Number (GRN) within the 32 characters that make the CIM name. The GRN represents the geographical location of the asset. A 12-digit GRN provides the geographical location of a point within 1-metre resolution and will be defined by the network model team.

Hence, the structure of the name used in the network model will be: Asset Name (13 characters)
_Asset Type (3 characters) _GRN (12 characters)

Table 2. Asset types and the abbreviation used in the CIM name

Asset type	Code
Battery	BAT
Diesel	DIE
Demand Response	DSR
Electric Vehicle	EV
Electric Vehicle V2G	EVG
Hydro	HYD
Solar Photo Voltaic	SPV
Wind	WIN
Other	OTH

Each asset providing flexibility has a 'dual' representation in the PSA model:

- a) One for accommodating the forecasted active power value of that asset (base value)
- b) Another one representing the flexibility offer from the NMF (delta flex value). This one will be distinguished by adding "_F" at the end of the name

For example:

- a) EXAMPLE_HYD_SP1234567
- b) EXAMPLE_HYD_SP1234567_F

This dual representation was required as it could be possible that the generation output expected from a resource as created by the internal DSO Operational Forecasting tool might not completely align with the flexibility offer provided by that same resource to the market via the NMF. To avoid power flow model infeasibility, then this dual representation allowed both views to be captured in the model without creating numerical issues.

3.3.2 SSEN naming convention for electrical equipment

The SSEN BAU convention for naming network assets,] will be used to have clear and unambiguous labelling for switchgear and network equipment and to ensure the nodal forecasts are correctly assigned to the PSA network model.

Table 3. Operating voltage nomenclature

Operating Voltage for Part One	Letter
132kV	A
66kV	B

33kV	C
22kV	D
11kV	E
6.6kV	F

Table 4. Equipment class nomenclature

Equipment class	Letter
Line or cable	L
Busbar section or interconnector (within substation)	S
Transformer on the HV side	H
Transformer on the LV side	T
Shunt compensator	K
Busbar coupler	W

Table 5. Switch functions

Equipment class	Number
Circuit breaker (excluding lines)	0
Circuit breaker (lines)	5

Table 6. SCADA Units nomenclature

Equipment class	Abbreviation
Voltage in kV	KV
Current in A	AMPS
Active power in MW	MW
Reactive power in Mvar	MVAR

Table 7 provides examples of electrical equipment and their naming convention.

Table 7. Examples of naming convention for electrical equipment

<u>Equipment class</u>	<u>Description</u>	<u>Substation location</u>
XXXX XXXXX MW	Active power measured at circuit breaker on the LV side of the 132/33kV	Local BSP

	<u>transformer 1, busbar A of Cowley Local BSP</u>	
<u>XXXX XXXX AMPS</u>	<u>Current measured at circuit breaker at head of 33kV feeder 4 from Cowley Local BSP</u>	<u>Local BSP</u>
<u>XXXX XXXX AMPS</u>	<u>Current measured at the circuit breaker on the LV side of the 33/11kV transformer of Cowley Local Primary</u>	<u>Local Primary</u>
<u>XXXX XXXX MW</u>	<u>Active power measured at circuit breaker at head of 11kV feeder 3 from Cowley Local Primary</u>	<u>Local Primary</u>

Confidential

3.4 Power Flow Sign Conventions

To avoid ambiguity, a power flow sign convention was agreed to ensure that the load in the WSC is displayed in the direction expected by SSEN engineers for demand and generation, respectively. The convention used in SSEN BAU displays (e.g., PowerOn) takes the busbar as a reference point, and can be summarised as below, and illustrated in Figure 14:

- Positive (+) for MW/MVAr flowing out of the busbar
- Negative (-) for MW/MVAr flowing into the busbar

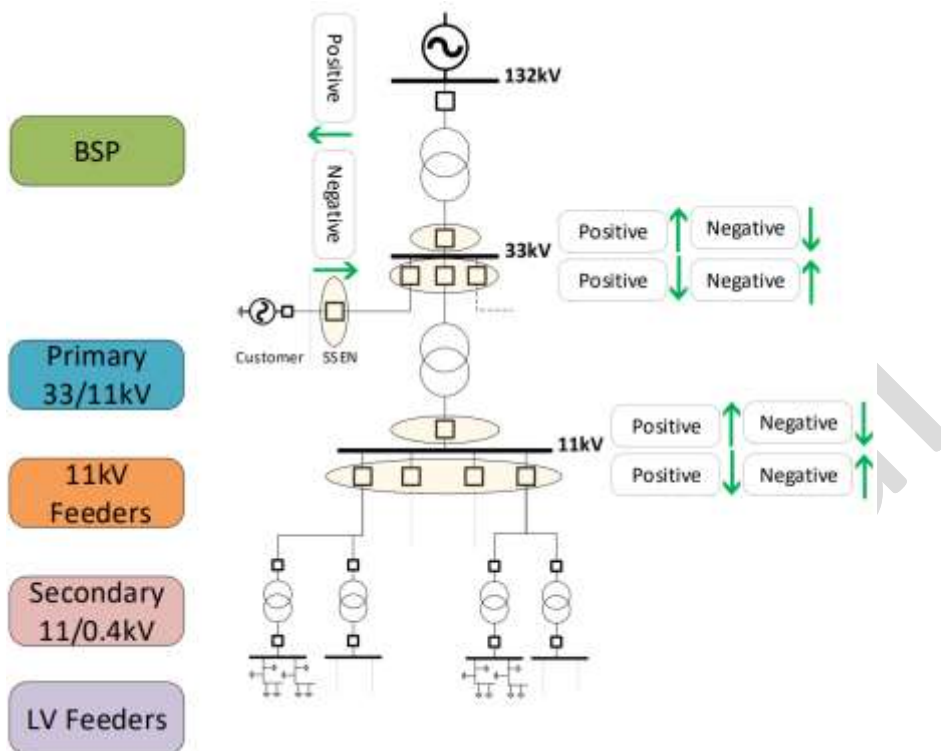


Figure 14. Power flow convention used in SSEN BAU systems

4 Data Requirements

To build a PSA network model, which is suitable for power flow studies, the following data is required as a minimum:

- a) Network connectivity and running arrangement (i.e., how the network components connect to each other and status of circuit breakers)
 - a. Running arrangement (i.e., status of circuit breakers due to outage/maintenance)
 - Automatic change-over schemes
 - b. Customer connectivity (i.e., where the customers are connected in the network)
- b) Transformer parameters (e.g., impedance, vector group)
 - a. Impedance and vector group
 - b. Tap changers (i.e., regulated busbar, target voltage, ratio, number of steps)
 - c. Ratings (e.g., seasonal and emergency ratings)
- c) Lines/cables parameters (e.g., impedance, length)
 - a. Length and total impedance
 - b. Ratings (e.g., seasonal and emergency ratings)
- d) Shunt capacitors parameters (e.g., rating, steps, target voltage)
- e) Earthing/Auxiliary transformers
- f) Demand data (i.e., power required by customers connected to the network)
 - a. For the Primaries in scope of TRANSITION, demand data for the 11kV feeders will be used and downscaled to the respective secondary substations
 - b. For the Primaries out-of-scope of TRANSITION, demand data aggregated at the Primary level will be used
- g) Generation data (i.e., output from generators connected to the network)
 - a. For generators connected at 33kV and above, data from SSEN's SCADA systems will be used
 - b. For generators connected at 11kV, market settlement data will be used
- h) Register of flexibility assets (i.e., which assets can change their demand/generation)
 - a. Flex assets connectivity (i.e., where these are connected in the network)
 - b. Flex assets capability (i.e., maximum export/import capacity)

GIS data is also beneficial for visualisation purposes but not required to run power flow studies.

4.1 System Planning BAU Models

In SSEN, the System Planning team are the main custodians of the 132/33kV network model for the SEPD and SHEPD license areas. System Planners work on specific areas of the network and have a specialist knowledge of the network and whether this is constrained at specific points. This level of knowledge is needed to decide which studies they need to perform under N-1, N-2 conditions to ensure security of supply is always maintained.

TRANSITION focuses on Oxfordshire and thus the focus is on the system planning model for the SEPD license area. The master model for SEPD was developed and is currently maintained in PSS®E 34. The pipeline of new connections is also included in the PSS®E network model and is used to perform assessments on whether a new connection request can go ahead or whether it triggers a network constraint and thus requires reinforcement (e.g., upgrading a line or transformer).

To maintain a sensible number of nodes and overall network elements, the master model was segmented on a BSP-by-BSP basis, except for Witney and Yarnton BSP. These two BSPs are meshed through the 33kV network (via Charlbury, Chipping Norton, Bledington and Leafield primaries), as part of their normal running arrangement, hence they must be considered as a single network model. Other BSPs can also be meshed as part of N-1 contingencies.

An illustration of a BSP model in PowerFactory is depicted in Figure 15. The 11kV feeders supplied by each of the Primary substations are depicted in separate SLDs to improve visualisation, Figure 16 provides an example.

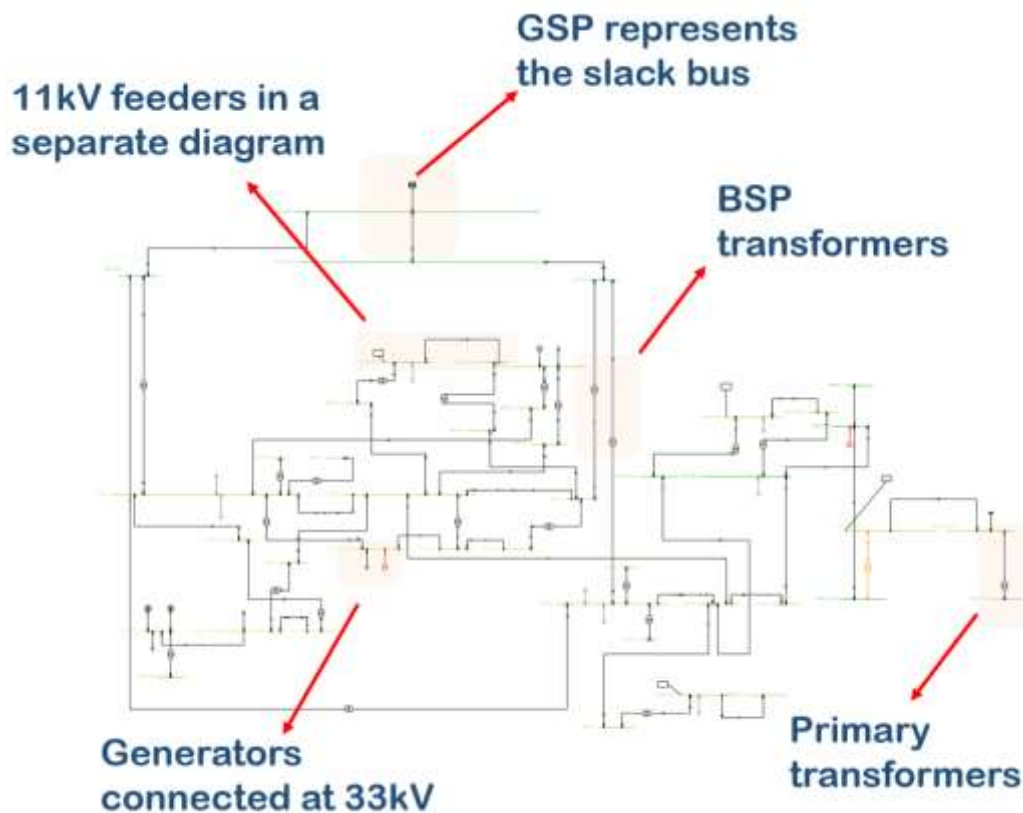


Figure 15. Illustration of an individual BSP model in PowerFactory

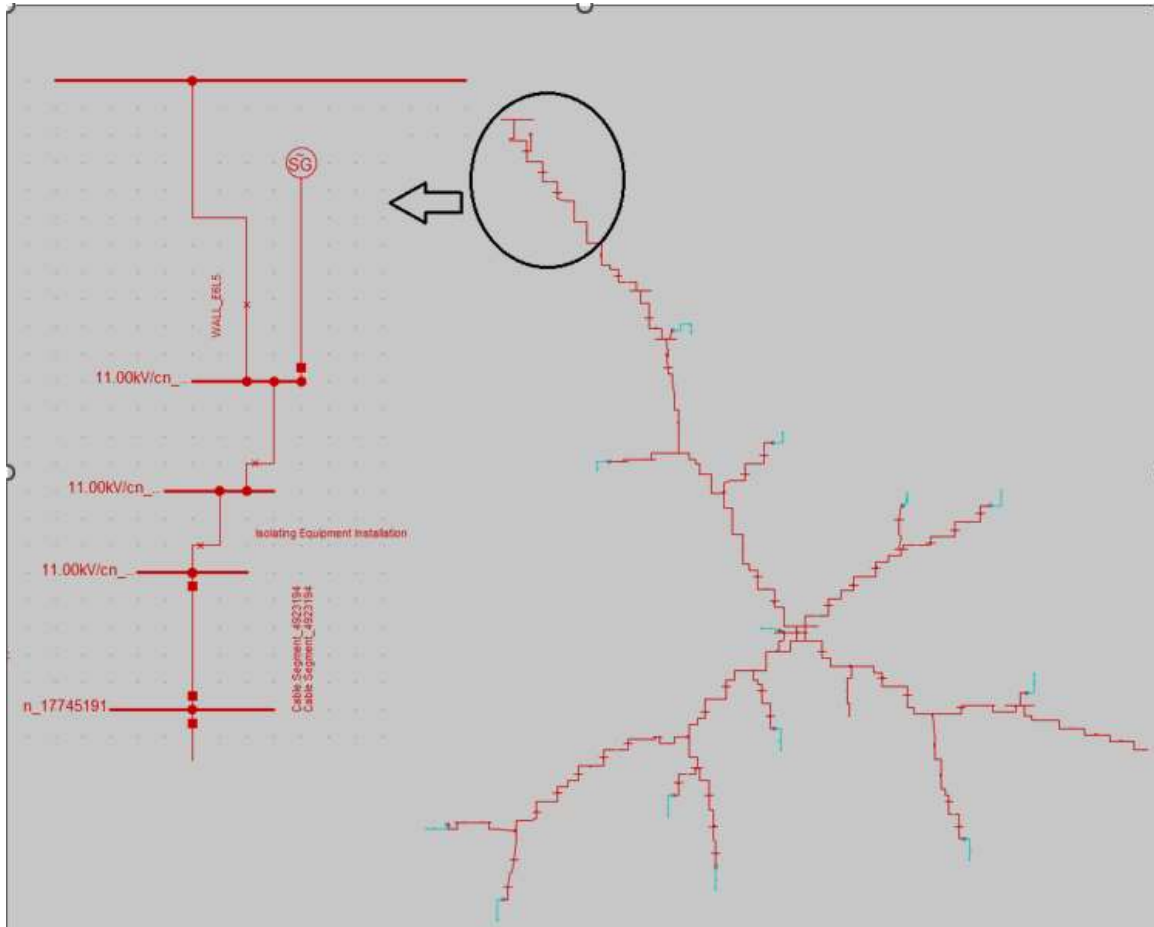


Figure 16: Example of Feeder WALL_E6L5 from the WALLINGFORD Substation in PowerFactory

4.1.1 Network meshing

The 132kV and 33kV networks are typically meshed in normal running arrangement. Because of this, the allocation of the slack bus (i.e., external grid) and the inclusion of the 132kV lines that supply the busbars are not trivial.

After running sensitivity studies of the power flows in the 132kV network above the meshed BSPs, SSEN decided that for this set of meshed BSPs, it would be sensible to include the 132kV lines connecting these busbars to the slack bus, as well as neighbouring 132kV busbars.

Witney and Yarnton are two BSPs with a meshed network at 33kV, which means that they need to be modelled together. This meshing has implications both for the network modelling perspective and for the flexibility market process (i.e., any flexibility dispatch will have an impact both BSPs).

4.1.2 Automatic (Auto) Change-Over schemes

Automatic (Auto) Change-Over (ACO) schemes are implemented in SSEN's network where it has been judged critical to maintain security of supply to a load or set of loads [8]. The ACO allows the

load to be switched automatically from one supply to another (e.g., a Primary can be transferred fully or partially from one BSP to another).

4.2 Network Planning BAU Models and the Connectivity+ Project

In SSEN, the Network Planning and Connections Design team develop models for parts of the 11kV network, when required by specific connection request from customers. These models are developed in PSS® SINICAL, a PSA tool targeted to the lower voltage levels of distribution networks. For historical reasons and because of the extent of the 11kV network, there is no BAU network model of the entire 11kV network.

SSEN is investing in building a connectivity model of the 11kV network to facilitate Open Data and to enable the DSO transition as part of the RIIO-ED2 regulatory framework. The Connectivity+ project is focused on correcting, validating, and exporting a connectivity model from SSEN’s GIS database, Electric Office, in a standard CIM format, for wider business use. The connectivity model can be exported as an electrical circuit in CIM, which can then be imported into PSA tools for power flow analysis without having to build a network model from scratch, as it’s traditionally done. A circuit trace of an 11kV feeder is shown in Figure 17.

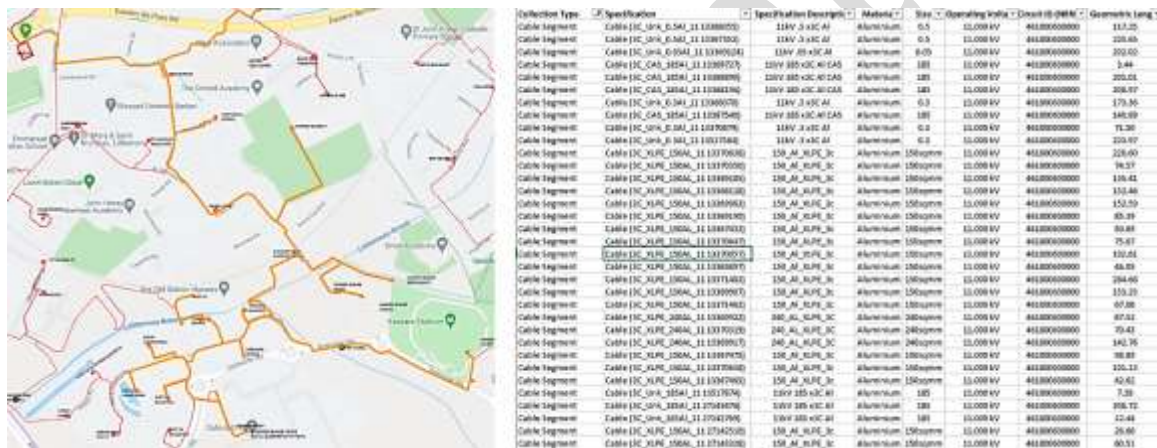


Figure 17. Example of a circuit trace (in yellow) of an 11kV feeder and the associated data. Provided by the Connectivity+ team.

As discussed before, SSEN’s version of Electric Office exports these circuits in CIM v15. Both PowerFactory and GridOS use CIM v16, hence a conversion is needed to make the Electric Office files compatible with both these PSA tools.

It’s worth noting that CIM files exported from Connectivity+ will be constantly evolving, as the physical network changes and the circuit identification methodology is refined. Thus, there is a requirement for a process that can ingest updated CIM files and produce an updated network model.

The 11kV HV network is operated on a radial basis and feeders can be meshed via Normally Open Points (NOPs). NOPs provide a way to isolate faults and interconnect feeders (i.e., reconfigure the network) to allow for supply restoration after a fault/outage.

4.3 Generation Database and Connections Pipeline

The SSEN Connections team also make modifications and updates to the 132/33kV network PSS®E model with the latest information on future and accepted connections in the SEPD and SHEPD license areas.

The TRANSITION project has the requirement to make sure the connections pipeline is considered, and the network model is updated accordingly to reflect any new generation that is accepted/connected to the network.

The generators typically have an installed capacity and a contractual capacity. The installed capacity is sometimes referred to as the physical capacity and represents the minimum between the generator installed capacity (e.g., solar panels) and the capacity of any upstream equipment resulting in a “bottleneck” (e.g., inverters and step-up transformers). The installed capacity is used to estimate the fault level contribution of the generator, whereas the contractual capacity is the maximum export capacity (MEC) in the connection agreement between the generator and SSEN. The MEC may be further curtailed if there is a flexible scheme in place (e.g., an active network management scheme). If a customer wants to increase its MEC, they need to apply for increased export capacity for SSEN to review and approve.

Normally, in the System Planning network model the generators connected at 11kV are represented as connected to the Primary substation LV busbar, whereas the TRANSITION model has detailed models for some of the 11kV feeders, thus some generators are connected along the 11kV feeder.

4.4 Transformer Parameters

As mentioned in the introduction to Section 4, key data needed to model the transformers include the number of windings, voltage level, planning and operational ratings and the tap changers.

For the TRANSITION project, there are 3 types of transformers considered in the network model:

- **BSP transformers**, which step down the voltage from 132kV to 33kV. These transformers have on-load tap changers that can adjust automatically to meet a target voltage.
- **Primary transformers**, which step down the voltage from 33kV to 11kV. These transformers also have on-load tap changers that can adjust automatically to meet a target voltage.
- **Secondary transformers**, which step down the voltage from 11kV to 0.4kV. These transformers have off-load tap changers and must be adjusted manually.

4.4.1 Planning and operational ratings

This section gives an overview of the ratings used for transformers, which are one of the main factors used when calculating network constraints and flexibility requirements. It also explains the equivalence between the ratings of transformers in PSS®E and PowerFactory for the 132/33kV network.

Transformers can have the following ratings [9], [10]:

- a) Continuous ratings or nameplate ratings: these relate to the design hot spot temperature (98°C) when the transformer has a continuous load, and the ambient temperature is 20°C. This results in a normal rate of ageing for the transformer
- b) Cyclic ratings: is a temporary rating corresponding to a specific load curve for a defined period (e.g., 24 hours). This rating allows for periods of high winding temperature due to overload, as these are balanced by equivalent periods of time at lower load levels.
- c) Emergency ratings (long-time): intended for occasional use, ranging from days to several weeks to cover for outages for maintenance. Also referred to as Continuous Emergency Rating (CER)
- d) Emergency ratings (short time): intended for temporary loading conditions up to 30 minutes. These ratings are capped at 2 times nameplate for distribution transformers (i.e., connected at 11kV or below) and 1.8 times nameplate rating for power transformers below 100MVA.

Some transformers have both a continuous rating and a CER. For those transformers that do not have a CER, then the rating can be considered to be the continuous rating, thus a cyclic loading factor can be applied.

Each transformer in the SSEN PSS®E network model data has the parameters “Winding MVA Base” and “Rate 1, Rate 2 and Rate 3 (MVA)” values, which depend on the seasonal information (i.e., winter, spring/autumn, and summer, respectively). PowerFactory extracts the PSS®E information based on “Winding MVA Base” and assigns the individual rating information (rated power of the transformers and lines, short circuit ratio) depending on a created *characteristic*, which can be activated using the trigger function in PowerFactory. Similarly, the AC Lines Rate 1, Rate 2, and Rate 3 MVA values are passed from PSS®E to PowerFactory. However, in this case, PowerFactory uses the “Rate 1 (MVA)” and the “Base kV” to derive the “Rated Current” of the lines. Then, this value represents the “Rating 1_RATE1” in the created characteristic.

This trigger function identifies the line and transformer characteristics, for different seasonal rates (e.g., winter peak, summer peak) and selects them accordingly depending on the study case. The trigger function is shown in Figure 18. Thus, when trigger is selected as Rate1, the transformer and line MVA coefficients are given in current value column (summer peak) and the ratings are stored within a vector, as illustrated in Figure 19. The transformers and lines ratings are finally allocated, and they can be visualised in the *Characteristic* tab.



Figure 18: Trigger function for rate selection in PowerFactory

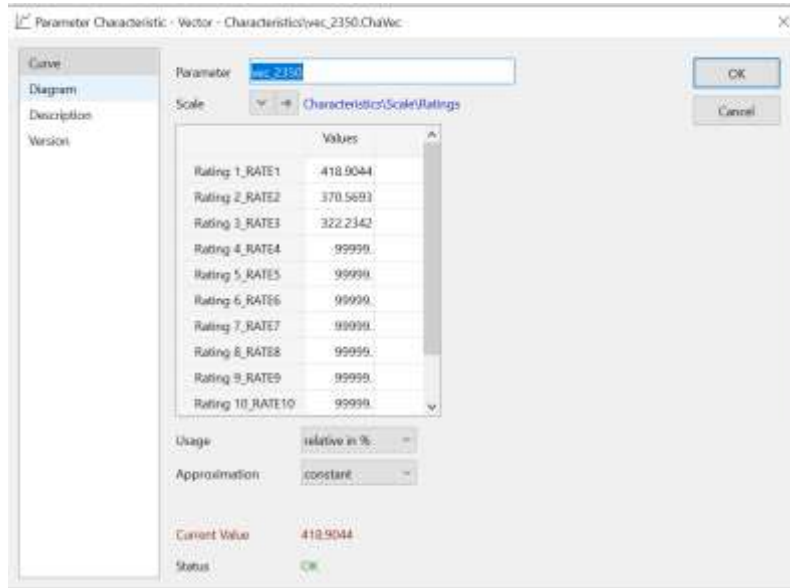


Figure 19: Vector characteristics for three different ratings: Rate 1, Rate 2 and Rate 3

If Rate 2 is triggered, the current values change. Thus, by multiplying the “Winding MVA Base” (transformers) and “Rated Current” (lines) values with a “current value”, PowerFactory provides the Rate 1, Rate 2 or Rate 3 values for both lines and transformers that are identical to the original ratings provided in the PSS®E original model.

Table 8 shows the ratings of the BSP transformers part of the TRANSITION trial.

Table 8. Ratings for BSP transformers in the Oxfordshire trial area

BSP	ID	Continuous rating [MVA]	Rating A (Winter) [MVA]	Rating B (Spring/Autumn) [MVA]	Rating C (Summer) [MVA]
Bicester North	XXMT	45	117	103.5	90
Bicester North	XXMT	45	117	103.5	90
Headington	XXMT	45	117	108	90
Headington	XXMT	45	117	108	90

Yarnton	XXMT	45	117	108	90
Yarnton	XXMT	45	117	108	90
Cowley Local	XXMTA	45	117	103.5	90
Cowley local	XXMTB	45	117	103.5	90
Cowley Local	XXMTA	45	117	103.5	90
Cowley Local	XXMTB	45	117	103.5	90
Drayton	XXMT	45	117	108	90
Drayton	XXMT	45	117	108	90
Drayton	XXMT	45	117	108	90
Witney	XXMT	45	117	108	90
Witney	XXMT	45	117	108	90
Oxford	XXMT	45	117	108	90
Oxford	XXMT	45	117	108	90

4.4.2 Voltage management and tap changers

Voltage throughout SSEN's distribution network is regulated mainly through the BSP and Primary transformers, which have automatic on-load tap changers and thus adjust automatically.

Based on The Electricity Safety, Quality and Continuity Regulations 2002, Section 27 [11], the following are the statutory limits for the different voltage levels in distribution networks:

Table 9. Statutory voltage limits

Voltage level	Upper/lower limits
132kV and above	±10%
33kV and 11kV	±6%
LV	+10%/-6%

SSEN engineers set the target voltages at the BSPs and Primaries LV busbars to a higher range (1.035pu - 1.025pu) than 1.0pu to avoid voltage problems at the customer point of connection downstream in the network and to reduce power losses. The transformer automatic tap changers then adjust during operation to maintain the voltage as close as possible to the target voltage.

The target voltage for the transformers is set at the automatic voltage control (AVC) relays. The function of the AVC is to ensure the voltage across the network is always within the statutory limits. The voltage ranges can vary over the summer and winter months and specific relays can change it automatically based on the season of the year. These seasonal changes are usually programmed into the local control systems within the AVC, as opposed to being actively managed by the control engineers in real-time. For example, the target voltage can be reduced to 1.01pu during summer if there is a lot of solar PV generation connected downstream from that transformer.

4.5 Cables and Lines Parameters

The total impedance for the overhead lines and cables on the PSS®E model is transferred directly to the PowerFactory model. For the 11kV network this is done separate, as the information is not included in Electric Office CIM export.

4.5.1 Planning and operational ratings

Ratings for the 132kV and 33kV overhead lines and cables come directly from the PSS®E network model, whereas for the 11kV network, the ratings are populated as part of the CIM conversion process with the information coming from an internal SSEN database of cable types.

4.6 Shunt and Fixed Capacitors

All SSEN-owned shunt capacitors are connected to the 11 kV network. There are capacitors at 132 kV, but they are operated by National Grid ESO rather than SSEN. The 11kV connected capacitors are not used to actively manage the voltage, hence their operation is not coordinated with the tap changers, they are only turned on/off.

4.7 Neutral Earthing Transformers

Neutral Earthing Transformers (NET) are auxiliary transformers, which are used to provide a low impedance path for fault currents to earth, as well as providing a low voltage supply required by ancillary equipment (e.g., cooling equipment and controls) [12]. These NET are connected to the LV side of BSP transformers.

4.8 Demand and Generation Data

Demand and generation data is needed to perform a power flow analysis. This can come either in the form of snapshot values (e.g., winter peak) or timeseries data. For the validation in PowerFactory, historical data from SSEN's PI historian was used to obtain winter peak values and stress test the network models.

4.8.1 Operational forecasting and downscaling

As discussed in Section 2.2, an Operational Forecasting tool is integrated to the WSC, to drive the network model and maintain an up-to-date state of the power flows in the network. The operational forecast developed by Sia partners will be able to provide a forecast for any generators and demand nodes that have a data stream (and enough historical data) available to train a forecasting model. The forecasting solution will be able to provide a forecast for most of the medium/large scale generators, as well as overall BSP and Primary substation underlying demand. As there is minimal data available for small scale generation sources (e.g., rooftop solar PV, EVs, small scale batteries),

as well as limited monitoring of secondary substation demand, then there is no ability to forecast those elements directly. Only generators connected directly at 33kV have data from SSEN PI Historian database, whereas those generators connected at 11kV have half-hourly settlement data. For a more in-depth description of the forecasting solution and its development, refer to the TRANSITION report in [13].

As illustrated in Figure 20, the operational forecasting engine will provide forecasts for the following:

- For the 7 BSPs of interest in Transition:
 - Net demand at the BSP substation transformer
 - Total generation at the BSP substation transformer
 - Total underlying demand at the BSP substation transformer
- For generators connected directly at 33kV:
 - Total generation output
- For the 13 Primaries of interest in Transition:
 - Net demand at the Primary substation transformer
 - Total generation at the Primary substation transformer
 - Total underlying demand at the Primary substation transformer
- For each of the 11kV feeders coming out of each of the 13 Primaries:
 - Net demand at the head of the 11kV feeder
 - Total generation at the head of the 11kV feeder
 - Total underlying demand at the head of the 11kV feeder
- For generators connected directly at 11kV:
 - Total generation output

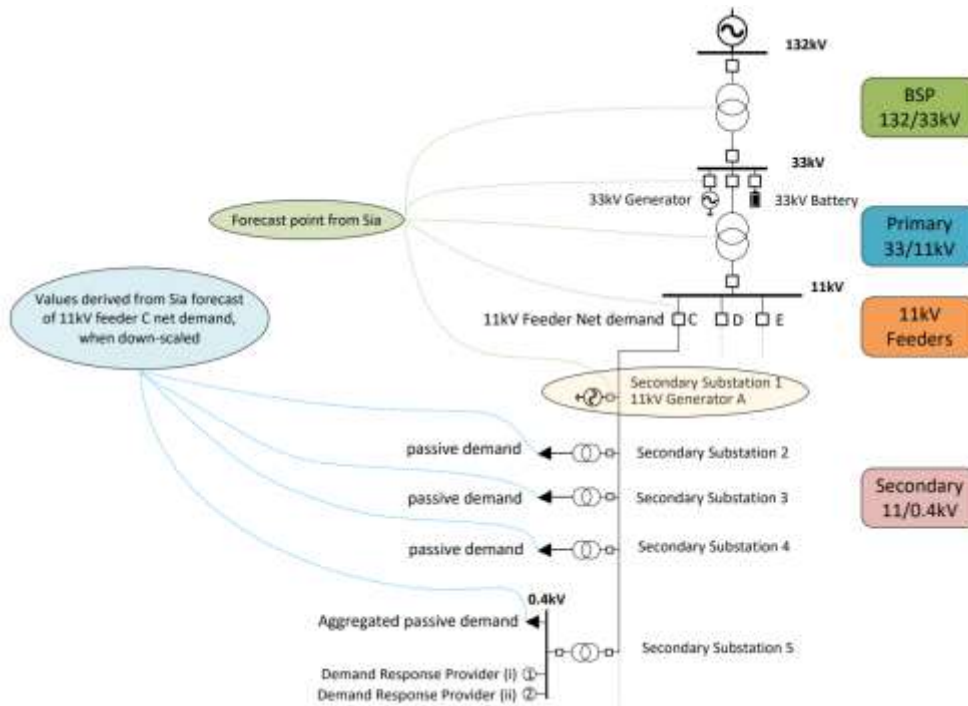


Figure 20. Illustration of points in the network where forecasts are provided, and values derived

As the lowest level of real-time demand forecasting available within the PSA model was at the top of the HV feeders, while within the model we have a full representation of all the secondary substations within the HV feeders, then a means to downscale that forecast from HV feeder total to each of the HV/LV substations below that, was required. This was attributed as the “forecast downscaling” task.

Figure 21 shows an example of an operational forecast of the net-demand, the underlying demand and the generation on a given 11kV feeder. The value of underlying demand is the one that needs to be downscaled to the secondary substations connected to that feeder. Forecasts for the individual generators connected along the 11kV feeder are assigned individually as needed.

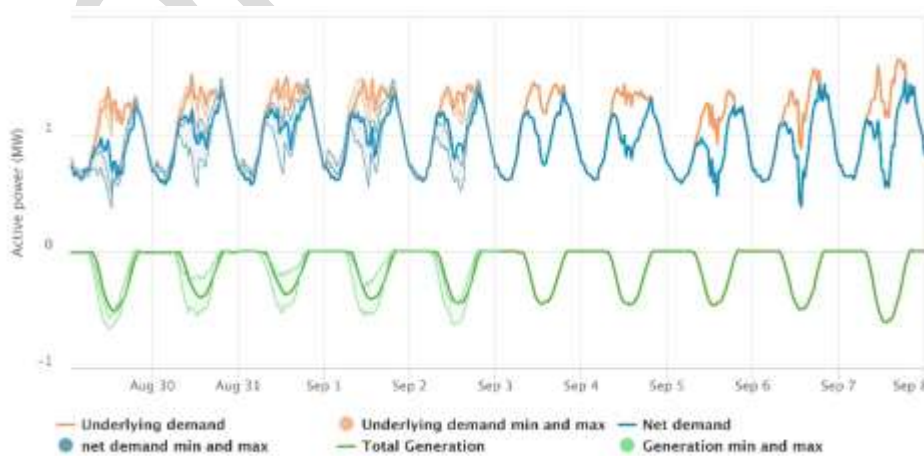


Figure 21. Example of a 10-day ahead forecast of net demand, underlying demand, and generation

It's worth noting that there is a possibility that the OPF encounters an infeasibility as part of the downscaling process due to misalignment between the forecasts and the apparent power ratings of the secondary transformers. For example, if the forecasted load is much greater than the rating of the transformer, this will result in a thermal overload as well as potentially an unacceptable voltage (i.e., below 0.9pu), preventing the OPF from reaching a solution. To mitigate this, an outer loop in the OPF can be considered to check that the forecasted load is less than the kVA rating of the transformer. Although this is not entirely realistic and disregards the possibility of overloaded secondary substation transformers (e.g., due to customers connecting more EVs and heat pumps), because the TRANSITION tools will be deployed in an operational context they need a high level of reliability, this is seemed like a compromise to facilitate the implementation.

In the future, SSEN will look to ensure the downscaling process is robust enough to handle this type of cases and that the OPF has preventive mechanisms in place to prevent infeasibilities, whilst reflecting the true aspects of the network.

4.9 Flexibility Assets

To understand whether flexibility can be used to alleviate a constraint, it is essential to represent those assets that can flex their demand/generation when receiving a dispatch signal. For this reason, the register of flexible assets needs to form part of the network model core dataset. The data source for these flexible assets come from industry actors, after they register for participating in the TRANSITION flexibility trials.

Flexibility assets are modelled in PowerFactory as synchronous, or static generators based on their characteristics. For instance, storage systems are modelled as static generators, whereas hydro power plants as synchronous generators. The name given to the flexibility assets in PowerFactory is limited by the number of characters accepted in the CIM CGMES format, and thus, a maximum of 32 characters are allowed.

Moreover, a flexibility asset in PowerFactory is modelled as two independent elements with identical characteristics (i.e., rated power, location, power factor, etc.), but different names differing by the underscore "F". The idea behind this dual representation is to provide a more flexible model to assign forecasts and dispatch flexibility during the trials. For example, on some occasions the view from the DSO Operational Forecasting tool of the likely generation pattern from a particular asset may not be completely consistent with the intended flexibility provision from that resource itself via the NMF market tool. By having a dual representation of those flex market participant resources in the PSA model, each to receive either value, we can avoid any numerical infeasibility issues.

Network Model Validation and Maintenance

Once the 132/33/11kV network model was completed in PowerFactory, a process was established to validate it against both the original PSS[®]E model and the operational PowerOn model. This included a thorough verification of the electrical parameters (impedances, ratings, etc.), as well as testing the power flow convergence in the different PSA tools.

4.10 Quality control process

The first step to ensure the models are valid and ready to use is to verify the convergence of the individual 11kV feeders through power flow analysis. This process starts with the PowerFactory

CGMES tool for importing CIM data. Then, a quality control process is followed to ensure the accuracy and quality of the data used for building the models, initially provided as CIM files, is fit for power flow analysis. The procedure is depicted in Figure 22.

The quality control process starts with the network topology checking step. The objective is to compare the CIM models connectivity against the PowerOn single line diagram (SLD). The process also includes reviewing the conductors employed for producing the models and the completed network connectivity through the switch and circuit breaker elements.

Subsequently, a set of parameters for selected network component are reviewed. This step includes evaluating the lines, breakers/switches, transformers, shunt, and synchronous machine parameters. Figure 22 shows the completed set of variables assessed for each network element. Then, the load and generation set points already included in the CIM data file for the individual feeders are utilised for conducting a power flow study. The main purpose is to determine the voltage and current convergence within the model. If not obtaining voltage/current convergence, a re-evaluation of the network variables is carried out to find potential inaccuracies in the network settings (e.g., a line that is considerably longer than the rest or a transformer with a wrong kVA rating). If the model converges and none of these issues are found, the network model is ready to use for building the Primaries substations (i.e., bundling the 11kV feeders together).

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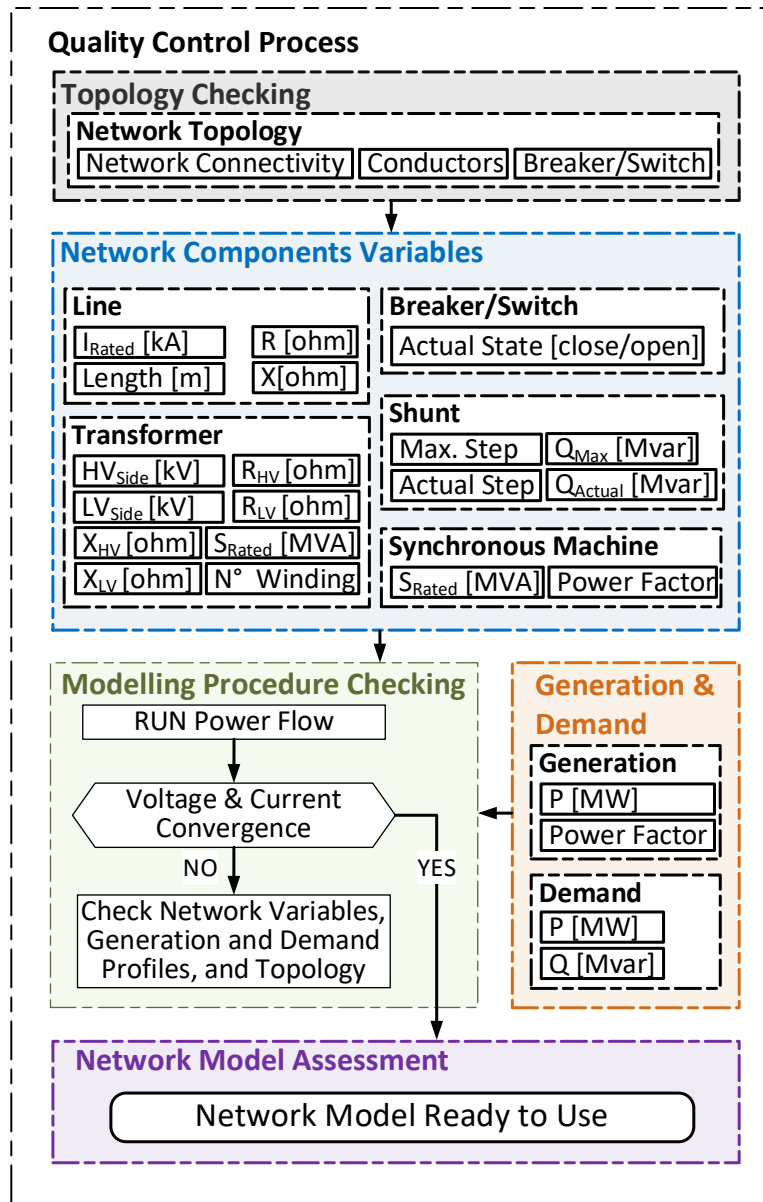


Figure 22: Quality control process for Primaries Substations Modelling

4.11 Issues Experienced using CIM for Interoperability Between PSA Tools

During the quality control process detailed in Section 4.10, some repetitive errors were found in the CIM files. Their description is as follows.

1. Number of phases of the element differs from the number of phases of the terminal to which it connects. This means that interconnection between elements with different phases is found in some cases. Particularly, between two phases and three phases, or elements with and without a neutral connection.
2. Power Flow errors that result in the Newton Raphson algorithm stagnating. In this case, the load exceeding the secondary transformer capacity was found to be the main cause.
3. No slack machine found. The whole network is de-energised. This occurred when first importing the CIM v16 files and doing an initial validation.

4. Switches connected between different voltage levels. This means that a direct interconnection (i.e., without a transformer) between two different voltage levels was found in some case. Particularly, between 6 kV and 11 kV.
5. Line elements such as length, current rated, and impedance values were wrong. Some of the lengths and thus the impedance was smaller/larger by 1-2 orders of magnitude.

An example is displayed in Figure 23. The red rectangle represents elements from the same feeder (i.e., ARNC_E2L5) connected at different phases. So, a three-phase busbar with and without a neutral conductor is interconnected to a two-phase element. The way these three elements are represented is not compatible in PowerFactory, resulting in power flow unfeasibility. Also, as highlighted in blue, there are busbars from different voltage levels present in Feeder ARNC_E2L5. Figure 24 shows that these busbars are directly connected, thus, resulting in power flow convergence issues. The errors mentioned above were resolved by OGS as part of a set of additional CIM processing steps described in Section 4.11.1, after which the feeders were imported back as CIM files into PowerFactory.

Name	In Folder	Grid	Out of Ser...	System Type	Usage	Phase Technology	Nom.L.-L. Volt. KV
cn_49182128	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49182169	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC-N	11.
cn_49182658	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49182688	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC-N	11.
cn_49182756	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	2PH	11.
cn_49182943	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49182944	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49182959	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49183006	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC-N	11.
cn_49183386	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC-N	11.
cn_49788964	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC-N	11.
cn_49788970	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49789075	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49789150	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_49789151	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_62819597	E2L5	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_63487515	11.00kV	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_97815014	E2L5	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	11.
cn_29557292	E2L5	Default Region	<input type="checkbox"/>	AC	Busbar	2PH	6.
cn_49181279	E2L5	Default Region	<input type="checkbox"/>	AC	Busbar	ABC	6.

Figure 23: Example of elements connected at different phases in PowerFactory

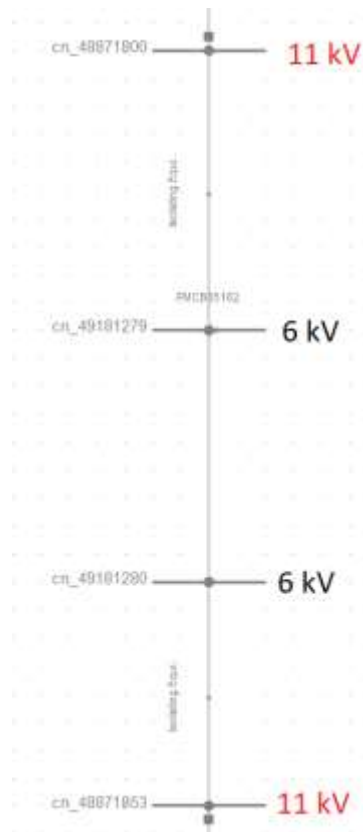


Figure 24: Example of elements connected at different voltage levels in PowerFactory

4.11.1 Further CIM processing and correction

As part of TRANSITION the data from Electric Office was to be loaded into DigSILENT PowerFactory for analysis. PowerFactory supports the ENTSO-E CGMES standard data, which was developed to support the exchange of balanced, transmission network models. As such there are some aspects of the distribution data from SSEN that were not compatible with the CGMES subset of CIM.

The changes below do not reflect any issues with the Electric Office CIM export, but instead describe additional steps that were taken to make the data align with a transmission-oriented format, CGMES, and compatible with a CGMES-compliant CIM importer (i.e., PowerFactory).

4.11.1.1 Adding dummy substation for Feeder switches

The Electric Office CIM export has switches that are outside the substation, representing switches on the feeder. The default containment for these would be within the Line container, as they are on the feeder often at a pole or cabinet. As CGMES is transmission-oriented it has rules that specify that any switchgear must be contained within a Substation.

An optional post-processing step was therefore added that would create dummy substations on the network to contain the switches and its *ConnectivityNodes*, within a single *VoltageLevel*. While superfluous from a topological perspective as it does not alter the network connectivity, it allowed the containment to validate for CGMES import in PowerFactory.

4.11.1.2 Transformer ratings

As discussed in Section 4.2, the parameters of the secondary transformers are not always included in the export from EO. For instance, while in some cases the transformer ratings were already present in the CIM export by EO, in others the ratings data was not present. Hence, to enable the power flow analysis, the secondary transformers required the ratings to be populated according to SSEN's Maximo database. Ratings were populated using the following logic:

- 1) If there is a rating in GIS that was populated from the Maximo Asset Database use this rating
 - a) If not, is the transformer Pole Mounted or single/split phase?
 - i) If yes and customers is < 3 make it 25kVA
 - ii) If yes and customers is 3-10 make it 50kVA
 - iii) If yes and customers is > 10 make it 100kVA
 - b) If not pole mounted and three phase:
 - i) If customers < 50 make it 200kVA
 - ii) Else if customers < 100 make it 315kVA
 - iii) Else if customers < 250 make it 500 kVA
 - iv) Else make it a default value (set to 500kVA)

A special case in this process is that some secondary transformers supply large commercial/industrial customers connected to the 11kV network. To avoid assigning a lower rating than required, these customers were validated using an extract of Maximum Demand customers (i.e., those with a connection agreement specifying a larger import capacity).

4.11.1.3 Primary substation supply

Where the feeders were to be used as stand-alone networks, the primary substation did not contain any form of generation. As such, the network was seen as being loads at the secondary substation without any form of in-feed from the grid. An *EnergySource* object was therefore created at the 33kV busbar at each primary substation to represent the in-feed from the primary network.

4.11.1.4 Force to balanced network

The data exported by Electric Office included some parts of the network that were either marked as being less than three phases, or where the phases were not marked. While the network does contain single- and two-phase sections, this is not supported by CGMES v2.4.15 or CGMES v3.0.0 which assumes a balanced, three-phase model. To allow the data to be imported into PowerFactory the network was forced to 3 phase with phase-code ABCN applied to all terminals.

4.11.1.5 Object naming limits

The ENTSO-E CGMES standard sets several limitations on object names (e.g., names cannot be more than 32 characters). The Electric Office export did not conform to this limitation as it is exporting CIM v15 for distribution. To remove warnings in the CGMES importer of PowerFactory an additional post-processing step was added to limit any names in the CIM data to 32 characters.

4.12 Power Flow Convergence

Making sure the power flow converges is one of the key validation tests that need to be carried out after building the network model. A power flow converges when the error (mismatch) for all the nodes in the network reaches the accepted tolerance (e.g., 0.1% is the default in PowerFactory). Several factors can lead to the power flow not converging, for example:

- Overloaded components (transformers and/or lines)
- Voltages falling outside of allowed upper/lower limits
- Transformers with tap changers that oscillate between tap positions and are not able to find the correct position to meet the target voltage (i.e., tap hunting)

In PowerFactory, two different formulations are commonly used to express the nodal equations of a network model: the Newton-Raphson current equation and the Newton-Raphson classical power equation as shown in Figure 25.

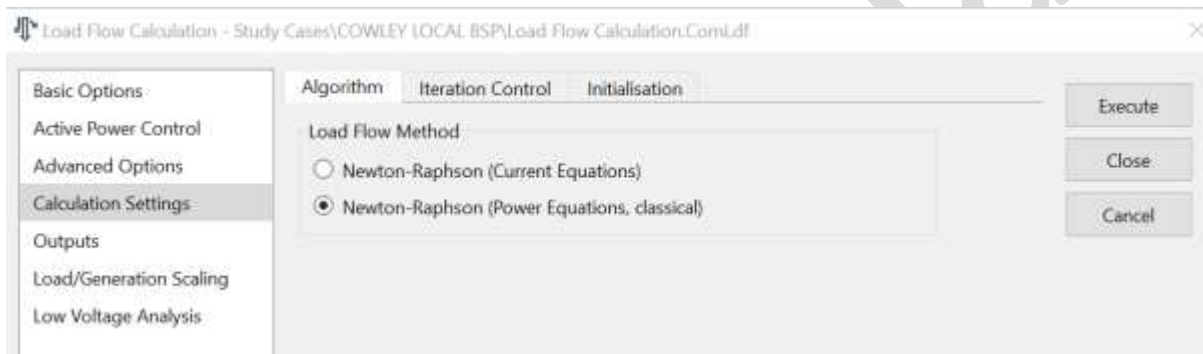


Figure 25 PowerFactory Load Flow Calculation

In both formulations, the resulting system of nonlinear equations must be solved by an iterative method. Depending on the type of network (distribution or transmission), the user can choose the method used to formulate the nodal equations. For large transmission systems, especially in peak load scenarios, the standard Newton-Raphson algorithm using the "Power Equation" formulation usually converges best. The "Current Equation" formulation is a common choice in power distribution systems, especially for unbalanced power distribution systems. The network model used in TRANSITION encompasses several voltage levels, so the choice of formulation and how this translates into different modelling philosophies will be discussed in more detail in section 4.13.1.

When considering the control characteristics of automatic transformer tap-changers and/or switchable shunts, PowerFactory applies an outer loop in addition to the Newton-Raphson iterations that solve the network nodal equations. Once the Newton-Raphson iterations converge to a solution within the defined tolerance, regardless of the setpoint value of the load flow defined in the control characteristics of the tap-changer/switchable capacitor, the outer loop is applied to achieve these target voltage values.

The actions taken by the outer iterative loop mainly include:

1. Increase/decrease discrete taps
2. Increase/decrease switchable shunt

3. Limit/release synchronous motor to/from max/min reactive power limit.

A final Newton-Raphson power flow iteration is performed to determine the new network operating condition. The power flow calculation settings are shown in Figure 26. It's worth noting that modelling the LV network was not considered for TP1, hence it was assumed that the network was balanced for power flow. Nonetheless, the LV network will be considered in subsequent trial periods. Section **Error! Reference source not found.** discusses this in more detail.

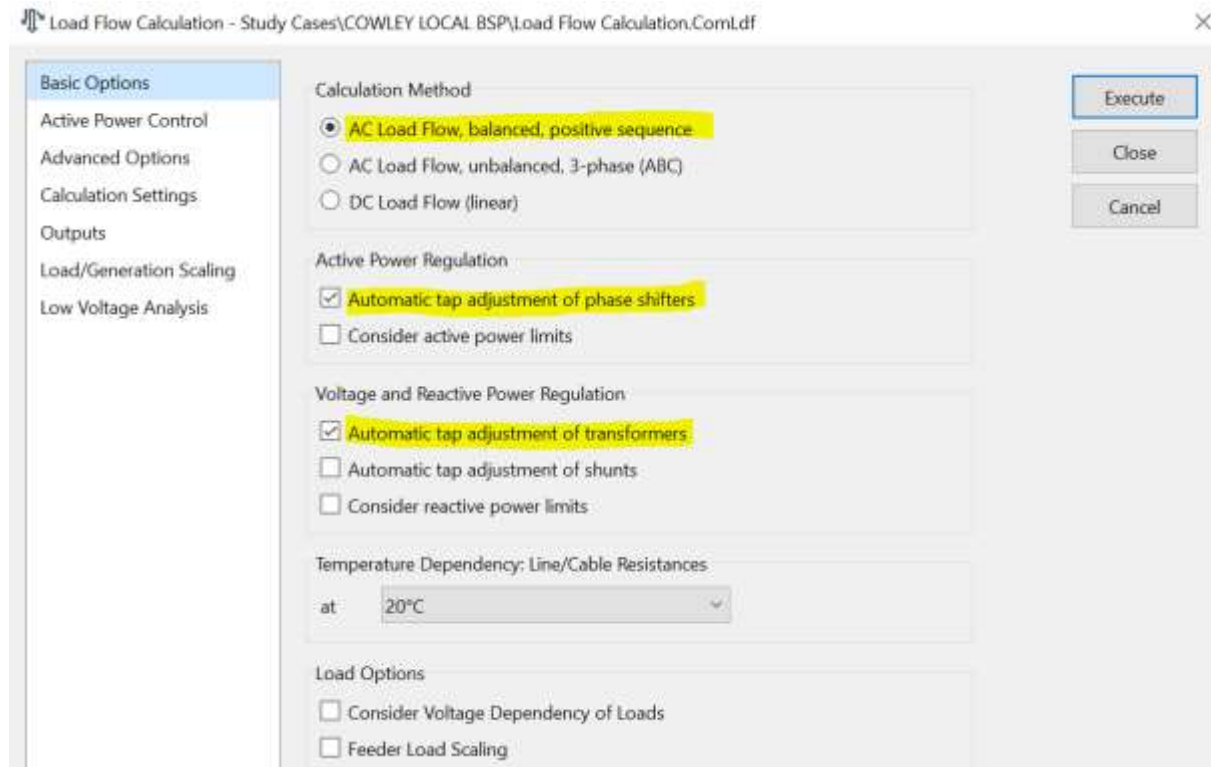


Figure 26 Basic Settings for Load Flow Calculation

4.13 Comparison and Calibration Across Different Tools

When comparing power flow results between PowerFactory and GridOS, discrepancies in terms of voltage profile and reactive power dispatch were identified which prompted further investigation. Certain modifications were required to be applied to the PSA model within GRIDOS to ensure that the model could run reliably therein and produce results consistent with PowerFactory.

4.13.1 Differences in modelling philosophy

Upon investigation, it was discovered that power flow discrepancies stemmed from modelling differences between PowerFactory and GridOS in terms of transformers, lines, and capacitors. Table 10 shows the changes that had to be made in the PowerFactory model or the CIM export to get matching results in GridOS. Further description of these changes is given in the following sections.

Table 10. Changes performed to network model in PowerFactory or the CIM export

Asset Modelled	Attribute	Justification
Lines	Removal of susceptance	<p>GridOS does not support modelling of susceptance for lines due to its focus on distribution networks. Given that the network is not modelling the transmission network, the impact of setting this parameter to 0 is minimal.</p> <p><i>Impact</i> Given the greater length of the lines, susceptance impacted the reactive power measured across the lines slightly.</p>
	Setting zero-sequence impedance to 0	<p>It was found that PowerFactory had some lines with rather large zero-sequence impedance values. PowerFactory computes a balanced 3-phase load flow, and it was found that varying the zero-sequence impedance did not affect the results. Nonetheless, these values were translated into the CGMES export and imported into GridOS, where zero-sequence impedance is accounted for in unbalanced 3-phased power flow.</p> <p><i>Impact</i> Reactive power of the overall network got affected by the high zero-sequence impedance values that some lines had in the original model.</p>
Transformers	Tap Changer position	<p>The PowerFactory model originally had tap changers modelled on the high-voltage (or primary) side of the transformers. GridOS models tap changers at the low-voltage (or secondary) side of the transformer. Thus, the winding ratio was inverted. When the tap positions were translated into GridOS they resulted in voltage step-downs rather than step-ups. To resolve this, tap changers were changed to the low-voltage side in PowerFactory.</p> <p><i>Impact</i> Voltage profile was greatly impacted by the previous position of tap changers, resulting in a whole step difference of voltage profiles between GridOS and PowerFactory.</p>
	Setting zero-sequence impedance equal to positive-sequence impedance	<p>To ensure that modelling of transformers impedance was equivalent between PowerFactory and GridOS, the assumption that in 3-phase transformers the zero-sequence impedance equals the positive-sequence impedance was made. This resulted in matching reactive power dispatch from transformers across both platforms. The justification for this assumption is seen below.</p> <p><i>Impact</i> Reactive power of the overall network was impacted given the differences in calculation of transformers' impedance.</p>
Capacitor	Power calculation	<p>When computing the susceptance of Y-connected capacitor banks, PowerFactory uses the capacitor's rated power and</p>

		<p>line-line voltage. GridOS in turn uses the line-neutral voltage. To account for this difference, the capacitor rated voltage was converted from kV-LL to kV-LN in the CGMES export.</p> <p>Impact Reactive power of the overall network was impacted, given that the susceptance of the capacitor was calculated differently.</p>
Load Types	Modify to constant power	<p>It was found that one load type was defined incorrectly in PowerFactory. Namely, the Lod_ConstantPower, which had non-zero exponents. This was set to 0, as constant power loads have exponents set to 0.</p> <p>Impact Active and reactive power of the network was impacted due to the power consumption of the loads.</p>

4.13.1.1 Modelling Transmission vs Distribution

Another source of incompatibility stemmed from the modelling of transformer's impedance and susceptance of lines. GridOS considers unbalanced 3 phase transformers, and thus, considers the effects of zero-sequence impedance for transformers. However, this is not the case for PowerFactory. The CGMES CIM profile export from PowerFactory models the entire system as balanced and 3 phase. To align transmission and distribution modelling systems and analysis results, transformers were assumed to be modelled with zero mutual impedance between phases and cables. This resulted in having a more consistent reactive power dispatch between both platforms.

When assuming zero mutual impedance for transformers, the admittance matrix for a 3-phase balanced transformer becomes:

$$Y_{xfmr} = \begin{bmatrix} Z_{self} & Z_{mutual} & Z_{mutual} \\ Z_{mutual} & Z_{self} & Z_{mutual} \\ Z_{mutual} & Z_{mutual} & Z_{self} \end{bmatrix}^{-1} = \begin{bmatrix} Z_1 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_1 \end{bmatrix}^{-1}$$

Given that, by standard formulation:

$$Z_{self} = \frac{2Z_1 + Z_0}{3}$$

$$Z_{mutual} = \frac{Z_1 - Z_0}{3}$$

$$Z_1 = R_1 + X_1$$

$$Z_0 = R_0 + X_0$$

Assuming zero mutual impedance for balanced 3-phase systems leads to $z_0 = z_1$:

$$Z_{self} = \frac{2Z_1 + Z_0}{3} = Z_1$$

$$Z_{mutual} = \frac{Z_1 - Z_0}{3} = 0$$

4.13.1.2 Position of Tap Changers in Transformers

When exporting the data into CGMES files and carrying over the “current tap position” value to GridOS, it resulted in tap changers with positions ranging from 0 to -70. Since GridOS models tap changers at the secondary side (or low voltage) of transformers, these negative “current tap positions” resulted in a voltage step-down, as opposed to the voltage step-up observed in PowerFactory. Upon further inspection, it was noted that PowerFactory modelled tap changers at the primary (or high voltage) side of the transformers, which resulted in an inverted winding ratio.

From this finding it was concluded that the location of the tap changer was the root cause for the different voltage profiles on the overall network. To obtain better matching voltage profiles, the tap changers were relocated to the secondary side in PowerFactory. This led to smaller, positive tap positions that, in turn, resulted in voltage step-ups in GridOS.

GridOS has two control modes for tap changers and regulators: local and global. Local control mode has a target voltage at the transformer busbar and operates the tap position of the transformer to best meet the target voltage. Global control mode has a network target voltage band (e.g., 0.94 to 1.10 p.u.) and operates all globally optimised tap positions to meet this overall goal. When in global mode, it is possible that a particular transformer would have a voltage that is greater or less than the local control target to meet the network voltage targets.

4.14 Maintaining an Up-to-Date Operational Model

The physical network is changing constantly, and assets are connected, disconnected, transferred or upgraded. Consequently, the network connectivity evolves constantly with time; substations reach capacity and might require upgrades (e.g., new transformers) or new running arrangements are needed to facilitate new connections (e.g., transferring load to another substation).

Manual updates to different systems and databases are needed when physical changes occur in the network (e.g., Electric Office, Maximo, PowerOn, SIMS). Hence, there may be a lag between changes in the physical network (e.g., sites upgrade) and what is reflected in systems and databases. Moreover, because of the type of information held in the different tools some systems take longer to update than others (e.g., Electric Office vs PowerOn). PowerOn only stores the connectivity information and updates are done in advance of jobs being commissioned, while the Electric Office database takes longer to update given its geographical nature.

Because the TRANSITION network model is used to inform flexibility requirements during trials, there is a requirement to keep the model up to date, in particular the following components:

- Number of substations (ground- and pole-mounted)
- Network hierarchy (i.e., which BSP supplies which Primaries)
- Connectivity (i.e., where does a substation connect along a feeder)
- Normally Open Points (NOPs)
- Customers connected directly at 11kV, special arrangements

As explained in Section 3.1, the 11kV network model is extracted from SSEN’s Electric Office, as part of the Connectivity+ project. These connectivity models represent the physical network at the time the CIM files were extracted, hence these models might not align with the operational view of the

network held in PowerOn. Hence, there is a requirement to compare the 11kV network with the PowerOn equivalent connectivity model. Figure 27 provides an overview of the process followed to ensure the network model used in the TRANSITION trials aligns with the operational view of the network in SSEN's PowerOn.

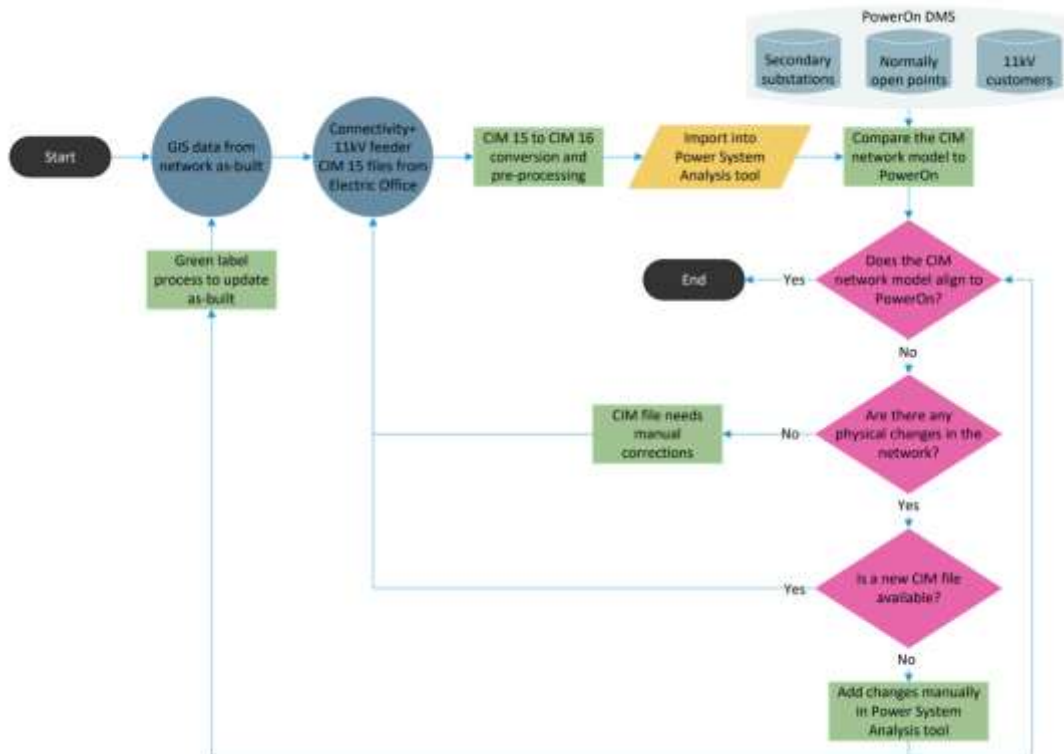


Figure 27. Process flowchart to align Electric Office extracts to PowerOn

Because of this, SSEN anticipates an initial model handover stage (from PowerFactory to the WSC) where the mainstay of the network and generation/demand representation data is shared, but also a provision of regular model updates whereby changes to the status of individual components can be updated in the WSC.

4.14.1 Alignment between Electric Office and PowerOn

The 11kV network models developed in PowerFactory were compared against the internal databases to ensure they represented the operational view of the network (i.e., the connectivity model in PowerOn). The idea was to find existing discrepancies between the two, regarding the number of 11kV feeders, Secondary substations, and numbers of customers connected. Firstly, as shown in Figure 28, a comparison of the existing 11 kV feeders in PowerOn and PowerFactory is conducted. The objective was to validate the accuracy of data from the CIM files containing the information regarding the network models. Secondly, a comparison of the number of Secondary Substations presents in the PowerFactory models with those existing in PowerOn is also carried out as illustrated in Figure 29.

11kV feeders PowerOn vs PowerFactory

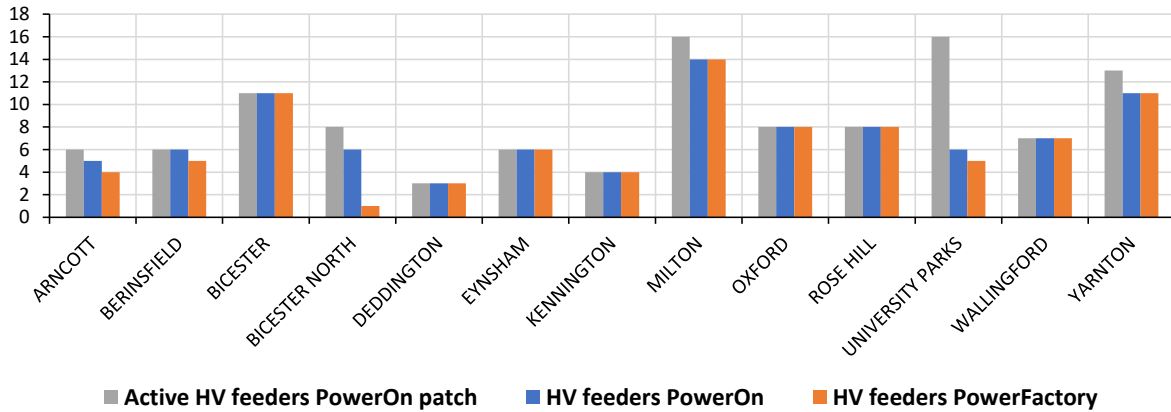


Figure 28: Graphical representation of 11 kV feeders in PowerOn and PowerFactory

Secondary substations PowerOn vs PowerFactory

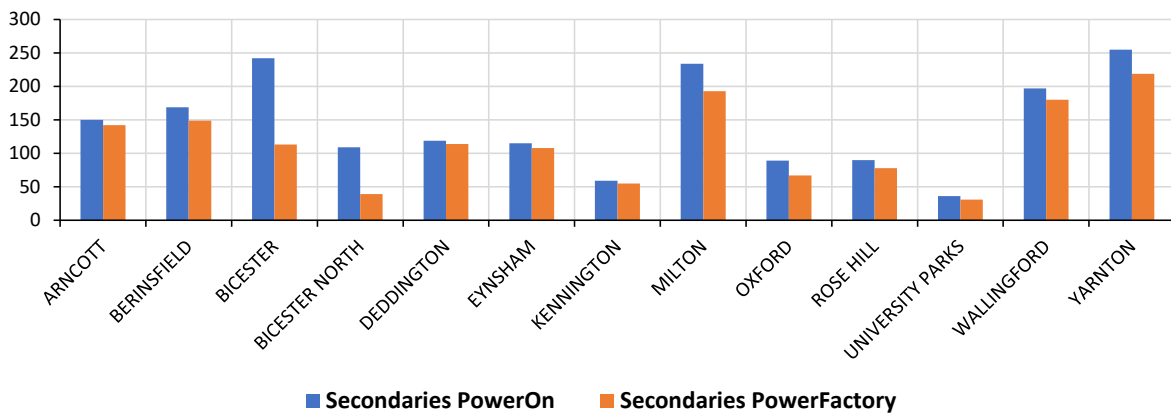


Figure 29: Graphical representation of Secondary Substations in PowerOn and PowerFactory

Those feeders with the highest discrepancies between the BAU operational model (PowerOn) and the TRANSITION model (PowerFactory) were manually validated by the Connectivity+ team and exported again from Electric Office to ensure the most up-to-date version was available. Then new CIM files were processed and imported back to PowerFactory to amend the required network sections. It is worth mentioning that some cases were amended manually (i.e., missing substations were added directly in PowerFactory) since no new CIM files could be produced.

One of the reasons for the discrepancies between PowerOn and Electric Office is that some of the network assets are missing in the GIS and the real-time connectivity, as seen in PowerOn, cannot be reconciled. Before this manual correction, the CIM export only contained part of the connectivity, omitting some of the secondary substations.

4.14.2 CIM difference files

After the initial model handover stage from PowerFactory into the WSC, there is the additional need to keep the two model in sync. While GridOS allows for the editing of network models in a GIS

interface, due to the nature of the project requiring several environments (development, testing, staging, and production), alternative methods were used to expedite the updating process.

Upon receiving notification of updates to the network model, a control version of the model was downloaded. The edits were then saved on the network model and an updated version was downloaded. These two CIM network models were then compared and subtracted to create a CIM difference model, which lists the addition, modification, and deletion of CIM objects and attributes. This CIM difference model was then applied to the other environments.

Another method was introduced where the newer network model was uploaded overtop the older model. This re-upload applies the addition and modification of CIM objects and attributes to the control model but cannot process the deletion of any CIM objects. A subsequent CIM difference model was created and then uploaded to capture these remaining edits.

4.14.3 PowerFactory network variations and versioning

The “Variations and Expansion Stages” feature in PowerFactory can be used to store changes to network data, such as parameter changes, additions, and deletions of objects. The function "Variation" is used to refer the change and expansion phases. Using Variations helps to record and track data changes in PowerFactory. Data changes stored in Variation can be easily activated and deactivated, which can also be permanently applied to the base network model when needed. Figure 30 shows the variation feature in PowerFactory.

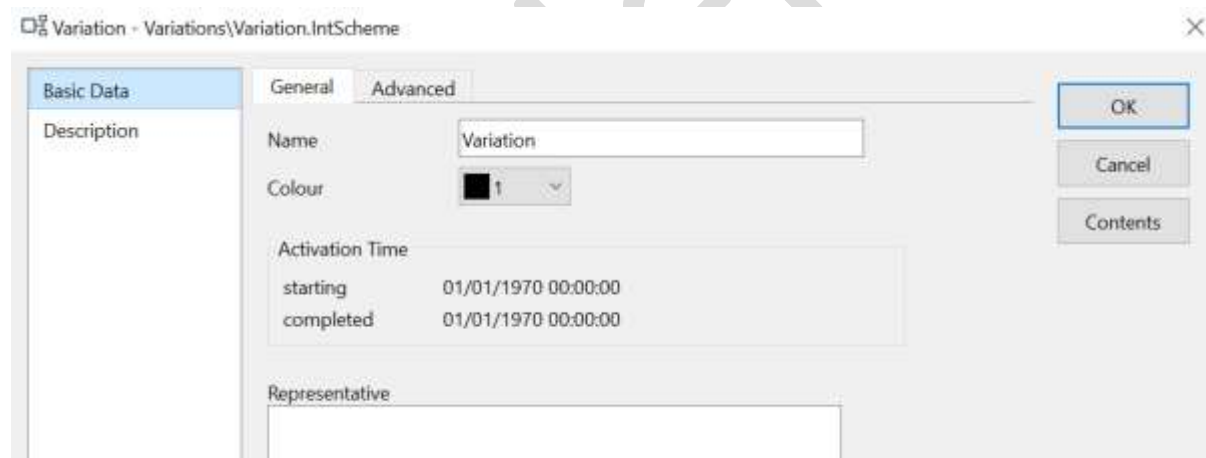


Figure 30 To Insert Variation Function in PowerFactory

The operational scenarios are typically used to store operational data such as generator scheduling, load demand, network line/switch status, etc. Operational data can be often distinguished from other component data because it changes frequently. Individual operating scenarios are stored in the operating scenarios folder and can be easily activated and deactivated.

5 TRANSITION PSA Workflow During Flexibility Trials

As discussed in Section 1.1.2, the PSA is used to calculate the flexibility required by the network, and to procure and dispatch this flexibility at different timeframes, as illustrated in Figure 3. The

timeframes trialled in TRANSITION are season ahead, week ahead, day ahead. The different steps where the PSA is used, and the timeframes are described in the following sections.

5.1 Needs Analysis, Total Contract Value, Offer Selection and Utilisation

5.1.1 Needs analysis

The goal of the needs analysis process is to determine how much flexibility is required, where in the network and when (time window). It consists of running a series of power flows to identify constraints in the network over a defined timeframe and horizon (e.g., a day, a week). The constraints are then translated into an amount of flexibility, that would be needed to alleviate the constraints, and a service window (i.e., an injection of 50kW over the hours between 17.30-20.30).

5.1.2 Total contract value and offer selection

Once the flexibility requirements are published on the NMF portal, and potential constraint resolution offers are received from flexibility providers, the next step is to run an OPF to identify the potential offers that can best resolve the constraints and select those that result in the minimum availability and utilisation cost (this is referred to as Total Contract Value or TCV).

5.1.3 Utilisation and dispatch

Closer to the time when the constraint will become active in the network a power flow assessment is run and used to make a decision on the actual amount of flexibility that needs to be dispatched. The output of this stage is a list of dispatch instructions for every flexibility asset that will be required to activate to resolve the forecasted constraint in the network.

5.2 Flexibility Market Timeframes

The relevant timeframes of commercial markets assessed in the TRANSITION trials can be summarised as:

- Season-Ahead: longer term contracts set months in advance (using an offline PSA model assessment)
- Week-Ahead: week ahead contracts and peer-peer capacity trades approvals (using the operational version of the PSA models derived)
- Day-Ahead and Intra-Day: flexibility service dispatch activities, while accounting for any cancelled trades in the intervening periods since the week-ahead contracts were set (using the operational version of the PSA models derived)

In later trial periods TP2 and TP3, then more complexity of flex service contracting and approvals across all timeframes will apply.

5.3 Performance Testing

This section provides some of the results obtained when testing the performance of the PowerFactory 132/33/11kV network model.

5.3.1 High-level results for the Oxfordshire area

High-level results for the Cowley Local BSP are included in the following section.

5.3.1.1 Cowley Local BSP

This section reviews the results obtained when analysing the Cowley Local BSP for different scenarios, including N-1 and N-2 contingencies.

Cowley Local BSP has a total of 2,572 lines with the majority of these being part of the 11kV network (2329). There are only 13 lines in the 33kV network upstream.

Base case

In the base case there is 1 line on the ROSH E6L5 feeder which is overloaded (Cable Segment_13369123). After inspection of the rating of this line, and when comparing it to the rest of the lines in that feeder, it became apparent that the rating was not correct, as the value was one order of magnitude smaller than the cables before and after. Hence, the rating was changed to match the preceding line. This resulted in no lines being overloaded for the base case.

From Figure 31 and Figure 32 it can be seen that all the busbars are within the voltage limits (1.06pu and 0.9pu) and majority are above 1.0 pu.

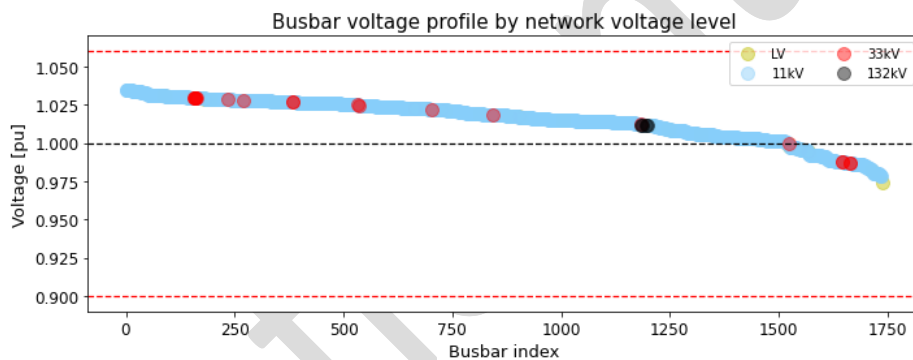


Figure 31. Voltage profile at Cowley Local BSP - Base case

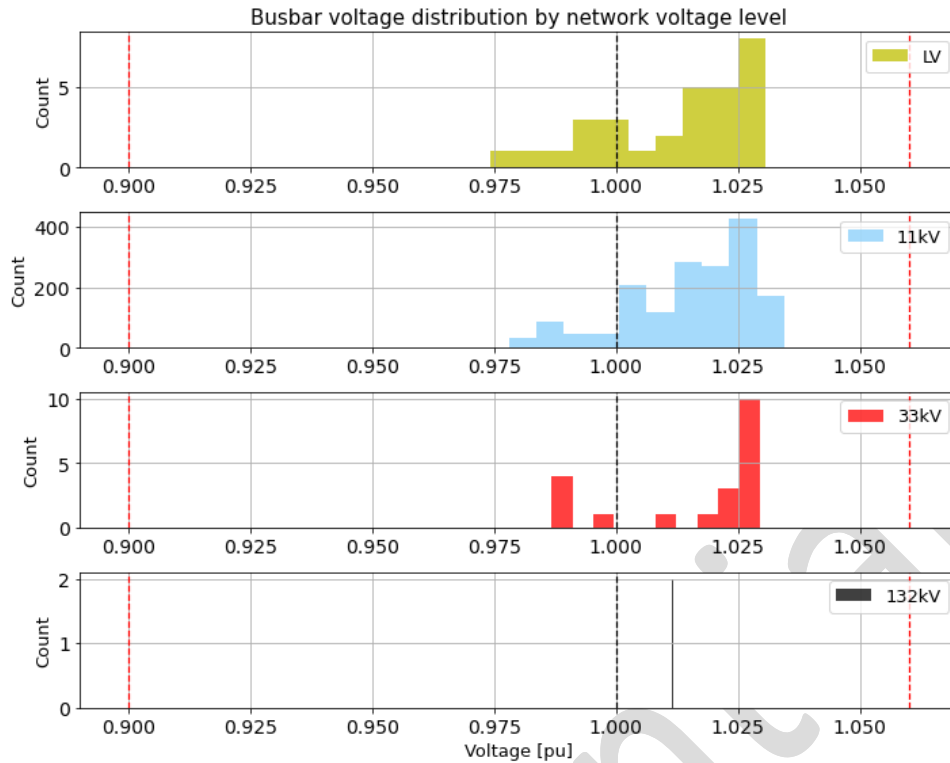


Figure 32. Voltage distribution at Cowley Local BSP - Base case

Figure 33 shows that all the transformers are within their loading capacity and none of them exceed 80%. It can be seen in Figure 34 that the 4 transformers in Cowley Local BSP, which are operated in parallel, have the same level of loading (less than 40%). The second transformer at Union Street (C2MT) has the highest loading of the Primary transformers. While the two transformers at Union Street are operated in parallel, they have different loadings (C2MT 67% and C3MT 48%), this is because the transformer have different impedances and different ratings. The effect of an N-1 outage at Union Street will be analysed to see whether this results in the transformer being overloaded.

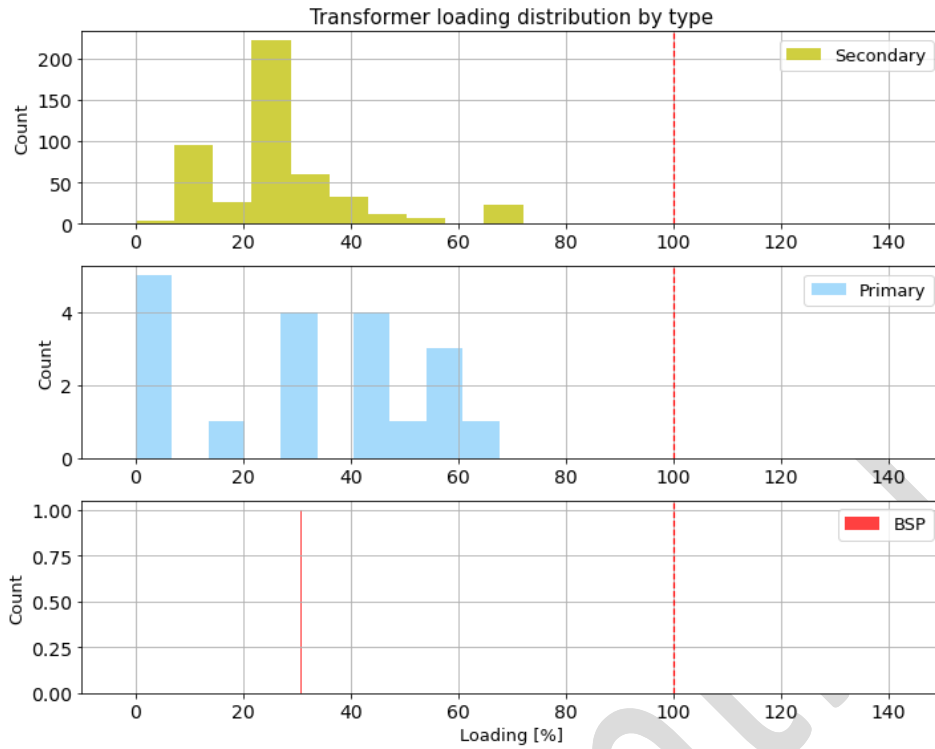


Figure 33. Transformer loading distribution at Cowley Local BSP - Base case

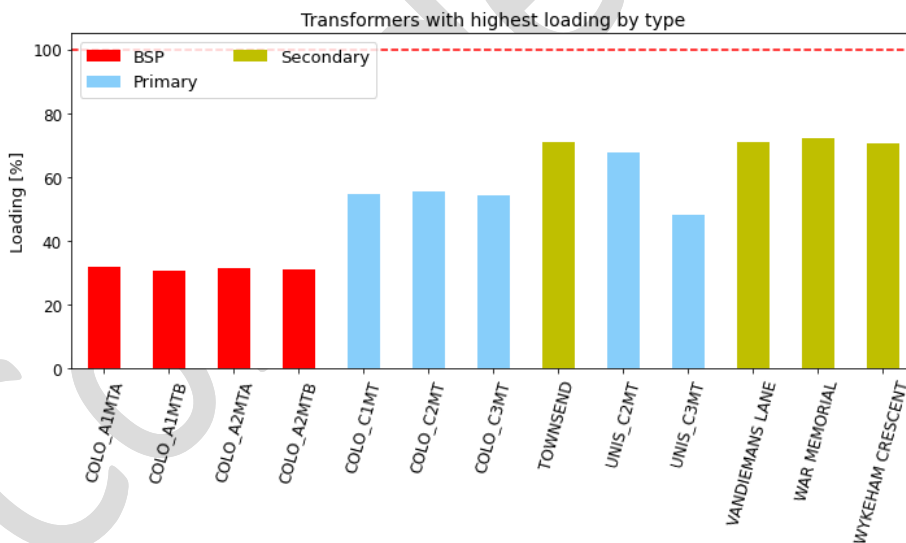


Figure 34. Highest loaded transformers at Cowley Local BSP - Base case

Figure 35 shows the loading distribution of the lines by voltage level. Majority of the lines on the 11kV feeders are loaded less than 40%, whereas some lines in the 33kV network are loaded at 60%.

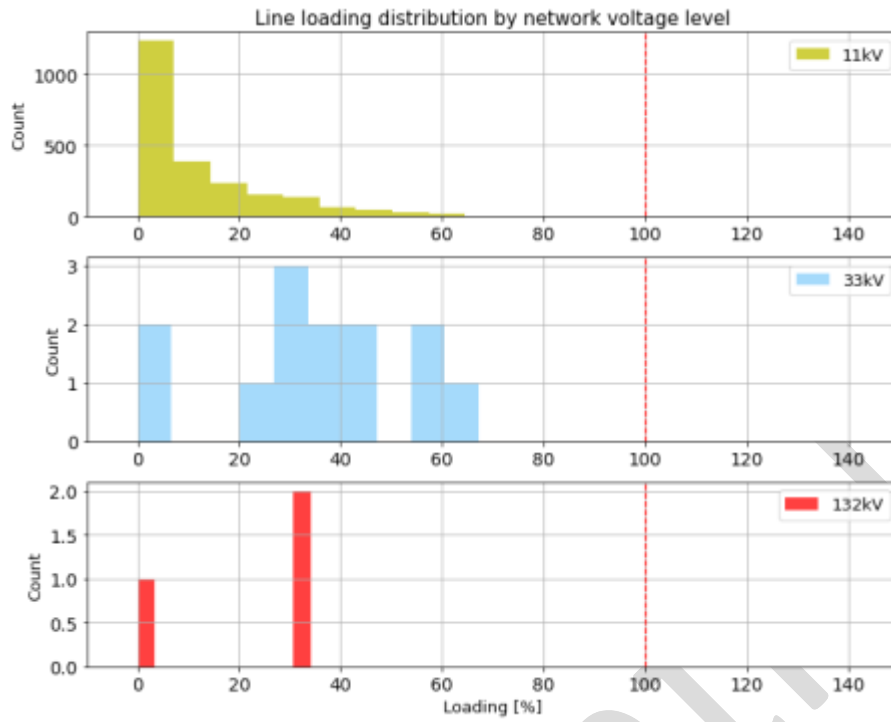


Figure 35. Line loading distribution at Cowley Local BSP - Base case

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6 Key Learnings and Conclusions

6.1 Key learnings

Because the process of building the TRANSITION network model uses data from several different sources and it is transferred across different PSA tools, the network model needs to be validated at each of the development stages.

The main development of the network model was carried out in PowerFactory and then exported to the WSC, where a different PSA tool is used for the trials, this means that there isn't a single source of the truth. Because of this, the power flow results of these two PSA tools need to be aligned. Additionally, if there are any changes to the physical network, these need to be reflected in both the PowerFactory model and the WSC model, which adds further complexity to the process and can lead to errors.

For instance, the CIM files exported from SSEN's GIS will be constantly evolving, as the network changes and the extraction methodology developed by the Connectivity+ project is refined. For this reason, the process of converting and pre-processing these CIM files into network models that are usable by a PSA software like PowerFactory needs to be as automated as possible, to allow for constant updates to be incorporated seamlessly.

Also, data can be lost when converting between different versions of CIM, depending on the profile being used (e.g., CGMES). This is an ongoing concern, as there are several conversion stages during the network development process. For instance, when converting from CIM v15 to CIM v16, the imbalance characteristic of certain parts of the network had to be changed to allow PowerFactory to recognise the data. Other parameters, such as the conductor name/type are not preserved during the conversion process because they don't form part of the CGMES profile.

Additionally, when building the network model in PowerFactory and incorporating the generators and flexibility assets, some parameters are specific to PowerFactory and don't form part of the CIM export. For example, the way PowerFactory stores the different ratings of the transformers (Rate 1, 2 and 3) is not compatible with CIM and thus this information needs to be passed to the WSC via a different mean (e.g., in a csv file).

To enable the maintenance of an operational network model, which is capable of informing flexibility requirements close to real-time, databases and systems (PowerOn/SIMS/Electric Office) need to be aligned as closely as possible. An option being explored is for the WSC to be able to interface with an external PSA tool, so that only one network model is maintained.

6.2 Conclusions

Relevant conclusions from the work completed to date can be captured as follows:

- Developing integrated models across multiple voltage levels (e.g., EHV and HV combined), that may have been traditional separate, is likely to be an important factor underpinning widescale PSA model flexibility market analytics in the future
- Good consistency and open availability of high-quality data, coming from, and used within various different sources and tools within a DSO business, is critical to scaling the development of these types of PSA models
- CIM interoperability of PSA tools is very desirable, and useful, but is arguably still developing and there is still much work to do.
 - Several manual, or automated fixes, were required as part of the CIM transformation and importing processes in this project, with the OGS Cimphony tool being a key solution used in the translation of formats
 - Further work may be needed to ensure CIM profile interoperability for distribution needs at the lower voltage of the network in the future:
 - The present CIM v16 CGMES profile in PowerFactory is presently targeted at EHV analysis, where multi-phase and unbalanced network modelling requirements are usually less important
 - Even with the same CIM version and profile used, sometimes, the PSA tools give slightly different results initially, without corrections being put in place to ensure consistency
- The network is constantly evolving in the real world, with operational switching, as well as new developments happening at pace in an ongoing manner. Procedures and processes need to be further evolved to ensure models can stay up to date.
- PSA model data gathering, model development and ongoing maintenance processes may need to be made more efficient, with less manual and more automated processing of the steps followed in this work, in order to be scalable in future, beyond the relatively limited area Oxfordshire project model.

7 Future work

The main body of this report details the work completed to support the development of PSA models and tools for the initial TRANSITION Trial Period 1. Further work will continue the refinement of these activities, in advance of and after the later Trial Periods 2 and 3. A summary of this anticipated future work can be outlined here:

Further expanding the modelling work to capture real time connectivity in the PSA model:

The PSA models developed to date have included all relevant switching nodes therein, so that future real time connectivity and topology changes can be applied to enable truly real-time reflective PSA modelling. However, this requires integration between the operational timeframe PSA tool, and the source of this real time connectivity data. The best source of EHV and HV connectivity data (i.e., the live positions of circuit breakers and switches and other isolation points) would be the PowerOn Distribution Management System. As the PowerOn system resides in the Operational Technology (OT) domain, which creates IT security challenges for an innovation project to connect to, then we are exploring a collaboration using the SSEN NERDA project outputs, which create an IT domain external portal interface to the data that is contained within some of the internal OT systems (e.g., Pi). Using the exposed Pi tags for e.g., Circuit Breaker status from NERDA, then we could update the PSA model connectivity assumed for the trials indirectly that way.

Exploring the ability to deploy DigSILENT PowerFactory in an Operational setting:

The main workflow created to date has been the development of the integrated EHV/HV PSA model offline in PowerFactory and then passing it via CIM interoperability processes to the PSA tool GRIDOS that is used in the online trial systems. We would like to explore the ability to deploy the PowerFactory tool in an online operational setting and explore the use of it as the key PSA online tool within the trials directly in that manner. This may require additional IT integrations work with the other existing systems and tools that form part of the TRANSITION architecture to date.

Expanding the PSA Modelling to capture elements of the LV Network as well via the LEO Smart and Fair Neighbourhoods:

The main version of the network model that was developed for TP1, included both the 132/33kV network and the 11kV network. One of the objectives of TRANSITION is to explore the inclusion of parts of the LV network in the PSA model as well, as many of the flexibility participants in the market are connected in this lower part of the network. As part of the collaboration with LEO, there is active research on local energy markets, and on how to enable participation of communities in flexibility markets. The Smart and Fair Neighbours initiative is part of this effort.

The 'Smart and Fair Neighbourhood' (SFN) programme will demonstrate how flexibility services can sit at the heart of a smarter, low carbon, locally focused, energy system. The trials will look at different approaches to flexibility at the grid edge. They will be used to explore how smart technology and new commercial models can create opportunities in a prototype local energy marketplace and help to understand how this can be delivered in an equitable and fair way for everyone in Oxfordshire.

Each trial will be based in a particular neighbourhood, linked to an electricity substation. SFN areas selected for the trials are those identified as those that are likely to face more challenges to network managers as patterns of demand and supply change. There are constant fluctuations in demand for electricity networks. Therefore, to balance supply and demand, the local network needs to be more 'flexible' and adaptive to changes.

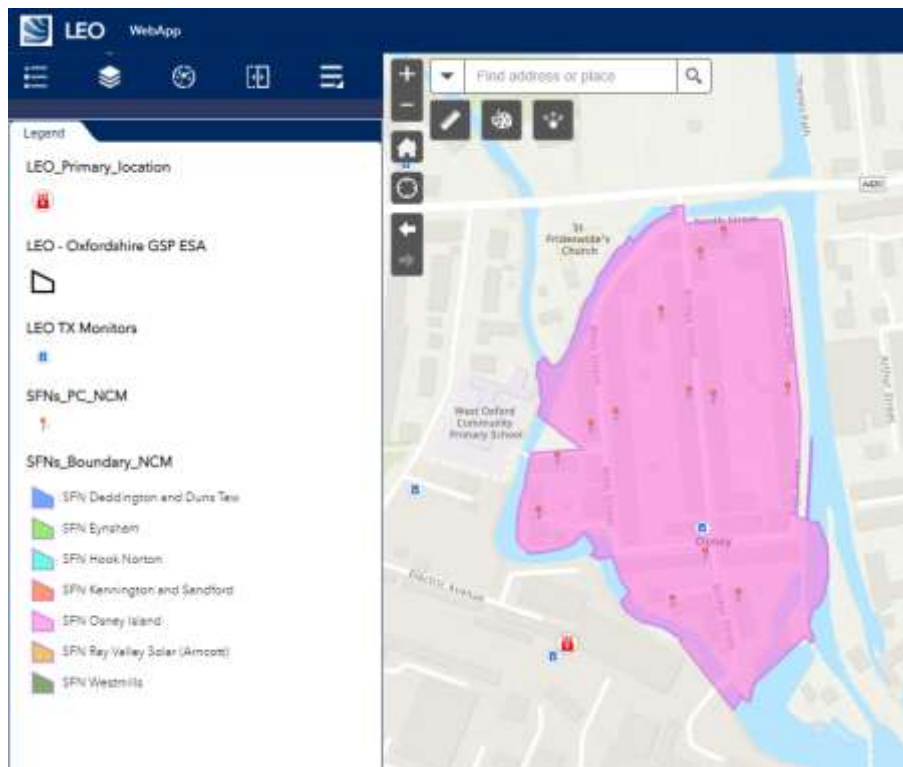


Figure 36. Illustration of the Osney Island SFN in the LEO WebApp

Including LV networks in the PSA modelling is anticipated to bring up several new technical and other challenges and opportunities that will have to be addressed:

- PSA technical challenges such as
 - o Full 3 phase modelling, and unbalanced load flow requirements
 - o Network connectivity uncertainties at LV level
 - o Ensuring the individual market zone PSA models do not become too large and unwieldy
 - o CIM interoperability for such networks
- Data Challenges
 - o Any uncertainties related to the existence of and the exact placement of low carbon technologies in the LV system
 - o Taking great care with individual customer data in a GDPR compliant manner

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