KASM SDRC 9.2: Contingency Analysis System Integration

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1 Executive Summary

1.1 Background

The Kent Active System Management (KASM) project aims to carry out a range of technical innovation trials to demonstrate more advanced operations and planning techniques for the 132kV and 33kV network in East Kent. It is envisaged that the project will deliver benefits that will span various areas, including the enablement of low carbon generation, the deferral of capital-intensive reinforcement associated with new generation connections and improved reliability of the network.

The last few years have seen a number of Grid Supply Points (GSPs) come under pressure from the level of embedded generation exporting power on the electricity distribution networks. In the most extreme form of the electricity network operating in the opposite way to which it was originally designed, whole sections of the network are not only supplying their own demand but are also exporting the surplus onto the transmission system. These conditions on the network can result in significant network constraints, which can impact existing generators as well as new generators seeking to connect to the distribution network.

The area of East Kent being used in this project contains four GSPs (of approximately 350 nationwide), and a fifth is being established in the area. Nevertheless, it currently requires as many as 34 contingency scenarios to be analysed in order to understand the network fully. The significant uptake of wind and solar generation in recent years, due to government incentives, and the presence of interconnectors connected to the transmission system, will only ever increase the number of scenarios that need to be analysed – there is no longer a simple ‘day of highest winter demand’ and ‘day of lowest summer demand’. There is more variation and hence a greater requirement to monitor all contingencies during real-time operation and future planning of the network.

Contingency Analysis (CA) is a valuable tool to understand more about the network and predict the effect of outages like failures of overhead lines, and to take actions to keep the distribution network secure and reliable. UK Power Networks (UKPN) will trial for the first time the use of CA on the Great Britain (GB) electricity distribution network. It will also be the first trial which utilises a coordinated data exchange with the electricity transmission network.

The KASM project will tackle and demonstrate the value of the Contingency Analysis System (CAS) in operational and planning time frames on the network in East Kent, delivering conservatively estimated net benefits of £0.4m for the project trial area in East Kent. Once proven successful, replication of this method across GB could conservatively provide net benefits of over £62m over the lifetime of the 45-year investment, when compared to business-as-usual (BAU) approaches.

This report (representing the project Successful Delivery Reward Criterion (SDRC) 9.2) focuses on the successful integration and testing of the CAS, including key lessons learned and identified risks.

1.2 Integration Architecture

The CAS integration architecture designed by the project covers the aspects of the different architectures aligned to The Open Group Architecture Framework (TOGAF). The Business, Data, Application, Technology and Security architectures are described in detail to illustrate the overall picture of the CAS. The main innovations in the architecture revolve around the enhanced Data Bridge, state estimation and real-time power flow solver. To ensure the architecture designed as part of the KASM solution aligns with the wider UKPN Information Systems strategy, the Logical Architecture Design Documents (LADD) were presented to a review board who approved several key principles of the project architecture.

In order to manage the complexities of sourcing data from multiple applications, the project developed an enhanced data mapping engine and Data Bridge which facilitates the build of a real-time power flow model. Conventional real-time power flow engines utilise state estimation as an input, however state estimation is not commonly available to DNOs due to the limited need to run real-time power flow calculations. In addition, the level of SCADA data available makes state estimation more complex than for transmission network operators, who have a richer source of SCADA data available. Through an innovative approach, the KASM project has worked with Bigwood Systems Inc. (BSI) to produce a State Estimator for the distribution network. The output from this
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can be utilised to perform real-time contingency analysis. The benefit of this can be derived in several use cases, including reliability management, outage management, and capacity management. As the level of embedded generation increases, the distribution network power flows become more dynamic – thus understanding real-time power flows becomes an important capability to manage the network efficiently and securely.

Integration with control room environments requires significant design considerations around security and resilience. The project has designed an efficient cloud infrastructure rather than using traditional physical hardware. This results in a reduced cost through smart server management, faster speed of deployment and improved reusability, whilst maintaining security of critical systems. This infrastructure allows future projects to easily build on the data available from the KASM project.

1.3 Testing

Developing new innovative tools requires rigorous testing before embedding products within BAU processes. To maintain clarity during testing, the project has created a detailed Test Strategy which covers the various elements required to validate the end product. Due to the complexity associated with development of the end solution for KASM, it was decided to approach the development in two phases. The first phase is the core product, which demonstrates the main functionality. The second phase delivers enhanced user functionality.

The project has successfully completed testing of the first phase, which was demonstrated to a wide audience including project partners and end users. Key elements of CAS functionality that were tested were:

- Importing of data from a range of existing applications
- Running state estimation using real-time SCADA data
- Running contingency analysis in a real-time and offline environment

This SDRC report provides a detailed approach to the testing conducted and presents the key evidence showing the tool being tested successfully.

Throughout the integration design and testing of the CAS a number of stakeholder engagement activities were conducted, including webinars, presentations and panel discussions. The project has incorporated feedback from these discussions within the integration design and has considered key principles within the Test Strategy. During the design and testing phase a number of lessons were learned and risks and mitigations identified. Key lessons revolve around data mapping, interfacing with multiple existing applications and testing of state estimation and power flow solutions. In addition to lessons learned, there remain key risks which need to be considered when integrating similar software in the control room IT architecture. These risks include the following:

- Ensuring up-to-date network models are used in the application – this is mitigated against by developing a robust network model change process
- Maintaining security using cloud infrastructure – this is mitigated against through careful design and penetration testing
- Guaranteeing active engagement with the solution from the end users – this is mitigated against by providing a clear end user training plan and early engagement in the design
# Definition of Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ARB</td>
<td>Architecture Review Board</td>
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<tr>
<td>BSI</td>
<td>Bigwood Systems Inc.</td>
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<tr>
<td>CA</td>
<td>Contingency Analysis</td>
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<td>CAS</td>
<td>Contingency Analysis System</td>
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<td>CEGB</td>
<td>Central Electricity Generating Board</td>
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<td>CIM</td>
<td>Common Information Model</td>
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<td>CPT</td>
<td>Cutover Process Testing</td>
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<td>DMS</td>
<td>Distribution Management System</td>
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<td>DNO</td>
<td>Distribution Network Operator</td>
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<td>DPF</td>
<td>Distribution Power Flow</td>
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<td>DSR</td>
<td>Demand Side Response</td>
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<td>EHV</td>
<td>Extra High Voltage</td>
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<td>ENTSO-E</td>
<td>European Network of Transmission System Operators for Electricity</td>
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<td>EPN</td>
<td>Eastern Power Networks plc</td>
</tr>
<tr>
<td>FALCON</td>
<td>Flexible Approaches for Low Carbon Optimised Networks (LCNF project by WPD)</td>
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<td>FEP</td>
<td>Front End Processor</td>
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<td>FTP</td>
<td>File Transfer Protocol</td>
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<td>GE</td>
<td>General Electric</td>
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<td>GEMA</td>
<td>Gas and Electricity Markets Authority</td>
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<td>GSP</td>
<td>Grid Supply Point</td>
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<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
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<td>HVDC</td>
<td>High Voltage Direct Current</td>
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<td>HV</td>
<td>High Voltage</td>
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<tr>
<td>ICCP</td>
<td>Inter-Control Centre Communications Protocol</td>
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<td>IEC</td>
<td>International Electro-technical Commission</td>
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<td>IEMS</td>
<td>Integrated Energy Management System</td>
</tr>
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<td>IIB</td>
<td>IBM Integration Bus</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>IS</td>
<td>Information Systems</td>
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<td>KASM</td>
<td>Kent Active System Management</td>
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<td>LA</td>
<td>Look Ahead</td>
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<td>LADD</td>
<td>Logical Architecture Design Document</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
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<tr>
<td>LCNI</td>
<td>Low Carbon Networks &amp; Innovation</td>
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<tr>
<td>LPN</td>
<td>London Power Networks plc</td>
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<td>LV</td>
<td>Low Voltage</td>
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<tr>
<td>MQ</td>
<td>Message Queue</td>
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<td>MQP</td>
<td>Message Queue Protocol</td>
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<tr>
<td>MVA</td>
<td>Mega Volt Ampere</td>
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<tr>
<td>MVar</td>
<td>Mega Volt-Ampere Reactive</td>
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<td>MW</td>
<td>Mega Watt</td>
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<td>NG</td>
<td>National Grid</td>
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<td>NPG</td>
<td>Northern Powergrid</td>
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<td>OC2</td>
<td>Operational Code 2</td>
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<td>Ofgem</td>
<td>Office of Gas and Electricity Markets</td>
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<td>PICS</td>
<td>Protocol Implementation Conformance Statement</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<tr>
<td>RT</td>
<td>Real-Time</td>
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<tr>
<td>RTU</td>
<td>Remote Terminal Unit</td>
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<td>SCADA</td>
<td>Supervisory Control And Data Acquisition</td>
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<td>SDRC</td>
<td>Successful Delivery Reward Criteria</td>
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<td>SFTP</td>
<td>Secure File Transfer Protocol</td>
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<tr>
<td>SPN</td>
<td>South Eastern Power Networks plc</td>
</tr>
<tr>
<td>TB</td>
<td>Tera Byte</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
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<tr>
<td>TLS</td>
<td>Transport Layer Security</td>
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<tr>
<td>TOGAF</td>
<td>The Open Group Architecture Framework</td>
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<td>TSO</td>
<td>Transmission System Operator</td>
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<td>UKPN</td>
<td>UK Power Networks</td>
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<td>OLTC</td>
<td>On-Load Tap Changer</td>
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<td>VM</td>
<td>Virtual Machine</td>
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<td>WAN</td>
<td>Wide Area Network</td>
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<td>WPD</td>
<td>Western Power Distribution</td>
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<tr>
<td>XML</td>
<td>Extensible Mark-up Language</td>
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</table>
3 Introduction

3.1 Purpose of Document

The purpose of the document is to describe the solution architecture that has been developed and delivered as part of the KASM project. In addition, the document will present the testing strategies and evidence of demonstrations through our testing procedure. The solution architecture provides the description of the system integration of CA software into UKPN’s systems. The design includes Business, Data, Application, Technology and Security architecture. The testing chapters within the document cover the Test Strategy and key evidence from the test procedures.

Key evidence criteria of SDRC 9.2:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Evidence</th>
<th>Section</th>
</tr>
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<tbody>
<tr>
<td>Completion of the system integration of Contingency Analysis software into UK Power Networks systems, excluding a real time link to NG</td>
<td>• Sign-off on set up of CA software</td>
<td>• Section 6</td>
</tr>
<tr>
<td></td>
<td>• Sign-off on successful demonstration and testing of CA software</td>
<td>• Section 7</td>
</tr>
<tr>
<td></td>
<td>• Published report on CA software integration that includes the control room IT architecture, lessons learned, engagement with other DNOs, and identified risks</td>
<td>• Section 5</td>
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<td></td>
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<td>• Section 7</td>
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<td>• Section 8</td>
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<td></td>
<td></td>
<td>• Section 9.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Section 9.2</td>
</tr>
</tbody>
</table>

Table 1: Key evidence criteria of SDRC 9.2 and corresponding sections of the document

3.2 References

<table>
<thead>
<tr>
<th>Number</th>
<th>Document Name</th>
<th>Author</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SDRC 9.3 – Installation of forecasting modules</td>
<td>Alex Jakeman, Sam Sankaran; October 2016</td>
<td>Alex Jakeman, Sam Sankaran; October 2016</td>
</tr>
<tr>
<td>3</td>
<td>Logical Architecture Design Document</td>
<td>Paz Mehta, Alex Jakeman, Gilbert Manhangwe, Chris Potter, Nathalie Beaufond; October 2016</td>
<td>Paz Mehta, Alex Jakeman, Gilbert Manhangwe, Chris Potter, Nathalie Beaufond; October 2016</td>
</tr>
</tbody>
</table>
## Requirements

Table 2 lists some of the key requirements for successful implementation of the CAS. The results of each test case are presented later in this document in section 7.8. Requirements related to performance, security and IT specific requirements are captured in the formal requirements matrix, which can be provided upon request.

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Category</th>
<th>Subcategory</th>
<th>Requirement</th>
<th>Test case(s)</th>
</tr>
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<tbody>
<tr>
<td>1.1.0</td>
<td>Contingency Analysis</td>
<td>General</td>
<td>The CAS must be able to operate in three distinct modes:</td>
<td>3.2.2, 3.4.2, 3.5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Using real-time data; CAS Real-Time mode</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Using historical data; CAS Study mode</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Future mode, using forecasted data; CAS Look-Ahead mode</td>
<td></td>
</tr>
<tr>
<td>1.4.0</td>
<td>Contingency Analysis</td>
<td>General</td>
<td>The real-time CAS should be able to conduct CA in pre-determined and configurable time intervals, report the results to the control room and store and archive each iteration.</td>
<td>3.5.3</td>
</tr>
<tr>
<td>1.15.0</td>
<td>Contingency Analysis</td>
<td>Power Flows</td>
<td>The CAS must model Full Generator Participation with Power at Risk – same as above except that the slack bus generator is treated as a normal generator and the delta generation to meet load demand is calculated and allocated locally/rank-wise/capacity-wise among all participating generators. All the generators at risk (i.e. where the allocated power is outside the limits of the generator operating region) are reported separately.</td>
<td>3.4.4</td>
</tr>
<tr>
<td>1.19.0</td>
<td>Contingency Analysis</td>
<td>Power Flows</td>
<td>The CAS must have options to set or import from the DMS, control limits to tap controller, generators and transformer controller, switched compensators and other component controllers.</td>
<td>3.2.5, 3.5.7</td>
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<tr>
<td>1.22.0</td>
<td>Contingency Analysis</td>
<td>Outputs and reporting</td>
<td>The CAS must retrieve, edit and store historical CA scenario data (including associated network topology) for network capacity management studies and analysis.</td>
<td>3.1.4</td>
</tr>
<tr>
<td>1.23.0</td>
<td>Contingency Analysis</td>
<td>Outputs and reporting</td>
<td>The CAS must provide data for outage management studies and analysis.</td>
<td>3.1.5</td>
</tr>
<tr>
<td>1.24.0</td>
<td>Contingency Analysis</td>
<td>Outputs and reporting</td>
<td>The CAS must provide data to support reliability management studies and analysis.</td>
<td>3.1.6</td>
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<tr>
<td>1.26.0</td>
<td>Contingency Analysis</td>
<td>Outputs and reporting</td>
<td>The CAS must support the view of study results over a set period of time for the entire network or set of components selected from the diagram or network model in standard spreadsheet format (table format) for further analysis. The data is exportable to standard spreadsheet format.</td>
<td>3.1.8</td>
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<td>1.28.0</td>
<td>Contingency Analysis</td>
<td>Outputs and reporting</td>
<td>The outputs from the CA shall be represented in a clear and concise format supported by data tables and a single line diagram which can easily be interpreted – both in Study mode and Real-Time mode.</td>
<td>3.1.9</td>
</tr>
<tr>
<td>2.2.0</td>
<td>Network Modelling</td>
<td>Data exchange</td>
<td>The CAS must have the capabilities to import different component ratings from the DMS and PowerFactory.</td>
<td>3.2.6, 3.5.9</td>
</tr>
<tr>
<td>2.7.0</td>
<td>Network Modelling</td>
<td>Network Definition</td>
<td>The CAS model must be capable of importing detail networks and equivalent networks (400kV, 275kV, 132kV, 33kV, 11kV).</td>
<td>3.1.14</td>
</tr>
<tr>
<td>2.9.0</td>
<td>Network Modelling</td>
<td>Network Definition</td>
<td>The CAS must have a flexible network model and allow for network updates based on changes in network detail and KASM network boundaries.</td>
<td>3.1.15</td>
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<tr>
<td>2.10.0</td>
<td>Network Modelling</td>
<td>Data exchange</td>
<td>The CAS must be able to exchange network models based on industry standard information exchange standards, i.e. Common Information Model (CIM) and PSS/E format.</td>
<td>3.1.16</td>
</tr>
</tbody>
</table>
The real-time CAS must use the network switch status and should reflect the connectivity arrangements taken from the DMS system. Any change in switch status or load must be reflected in the CA tool automatically and near real-time.

The CAS must perform data validations before execution of Load Flow calculations enabling accurate study results. Any assumptions used in Load Flow calculations shall be accessible to the user.

The CAS will be able to import the network model and its specifications from PowerFactory. The methods for integration must be robust, i.e. Common Information Model (CIM) and PSS/E format.

Table 2: Requirements for successful implementation of the CAS
5 Contingency Analysis Integration

5.1 Introduction

The KASM study area (East Kent) has in recent times become more challenging to manage both for the transmission and distribution network operators, partly due to increased distributed generation connected and increased flows on transmission interconnectors to continental Europe.

The CAS is a valuable tool to understand more about the network and predict the effect of outages like failures of overhead lines, and to take actions to keep the distribution network secure and reliable. The KASM project aims to introduce CAS as a tool to assist outage planners, infrastructure planners and control room engineers with the planning and management of the electricity distribution network.

The purpose of this section is to summarise the logical architecture of the CAS defined within the scope of the project. Although the project is only a trial, it is important that the underlying design is based on sound architectural principles, as it intended to provide the starting point for an enduring solution and a move to a possible BAU activity. The full description of architecture is contained in the LADD, which is available upon request.

The scope of the document is divided into the five architectural domains defined by the TOGAF ADM (Architecture Development Method):

1. **Business** – for the system users that will use the CAS, it describes the context in which the CAS will reside. It also outlines the current and to-be business processes

2. **Data** – describes the data that will be used in the CAS. The data is categorised and the sources of data are described. The network model used in the CAS is also covered

3. **Application** – describes the CAS and supporting software applications used to provide the data for contingency analysis

4. **Technology** – describes the IT infrastructure that will host the CAS

5. **Security** – describes the security considerations, including physical, communications and IT

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1 The Open Group Architecture Framework (TOGAF) is a framework – a detailed method and a set of supporting tools – for developing an enterprise architecture. For more information please see: [http://pubs.opengroup.org/architecture/togaf8-doc/arch/](http://pubs.opengroup.org/architecture/togaf8-doc/arch/)
5.2 Business Architecture

There is a strong focus among Distribution Network Operators (DNOs) to develop contingency plans to avoid or shorten outage periods when carrying out maintenance works, restoring power supplies to demand customers and maintaining routes for generation in the event of a fault. This section describes the business architecture at a high level. The details behind proposed business architecture will be covered under SDRC 9.6 (Development of business design to incorporate contingency analysis as business-as-usual), which is due in December 2017. It is envisaged that the trial period will help determine the future business process in greater detail.

Each of the Users has the responsibility of managing the power system in different timescales, as demonstrated in Figure 1 below:

- The control room engineer operates the distribution network in real-time.
- The outage planner is typically looking at the network within the next 1-7 days.
- The infrastructure planner is looking at the network in timescales that are months and often years ahead.

![Figure 1: Timescales of responsibility for network management](image)

To this effect, the role of control room engineers is to monitor the network in real-time, issue and manage safety permits to staff working on the network, and respond to faults by reconfiguring the network. The role of network management continues with outage planners, who specialise in maintaining and optimising the programme of outages to best serve customers. Finally, infrastructure planners maintain the design of the network and respond to new connection requests by identifying suitable points of connection to the network for major loads and distributed generation. Accurate real-time, short- and long-term planning is valuable in effectively managing the distributed resources, resulting in optimum use of the available network capacity.

5.2.1 Control Room

The role of control room engineers is to monitor the network in real-time, identify and mitigate harmful contingencies, issue and manage safety permits to staff working on the network, and respond to faults by reconfiguring the network.

Control room engineers use the PowerOn Distribution Management System (DMS) to perform their day-to-day task of managing and controlling the power system. In order to assist the engineers, the CAS will be deployed alongside the DMS. The DMS will send a real-time feed of data to the CAS application.

Using the CAS, the control room engineers will be alerted to future harmful contingencies in real-time. This capability will help control room engineers move from a reactive response to a proactive approach based on outputs from the CAS, which in turn will improve the reliability of the network.
5.2.2 Outage Planning

The role of outage planners is to carry out outage checks to confirm the feasibility of planned network outages. These checks are carried out through power flow studies conducted with the application PowerFactory and other necessary supplementary tools. The studies ensure voltage, thermal and fault level constraints are not put at risk during the outage. The studies help the outage planner to decide the best running arrangements of the network under the planned outage. If an alternative running arrangement cannot be determined, the outage planner will need to determine if generation needs to be curtailed in order to take the network outage.

Currently, outage planners manually analyse all possible contingencies to ensure that the outage plan is consistent with n-1 reliability requirements. Moving forward when the CAS is available, outage planners can use the automated CAS to run multiple contingencies in a number of seconds. The CAS will provide additional analytics facilities which enable outage planners to use forecast data to run studies rather than use ‘worst-case’ operating conditions (minimum demand and maximum generation) in East Kent. The overarching aim of using CAS is to reduce outage constraints on generators and the timescales required to analyse multiple contingencies.
5.2.3 Infrastructure Planning

The role of infrastructure planners is to manage new load and generation connections on the 33kV and 132kV networks. In addition, they manage ongoing reinforcement of the network to ensure security of supply. Like outage planners, infrastructure planners also use PowerFactory application to model new load and generation connections on the network. They currently perform these studies using worst-case operating assumptions.

Moving forward, using the CAS infrastructure planners will be able to model new connections based on realistic operating conditions which have been archived over a period of time. The archived scenarios will help them understand the coincidence of load and generation. Using more realistic operating conditions based on the coincidence of load and generation will reduce the expected reinforcement required for new connections. It will be important to manage the network closely in real-time to ensure the network is managed accordingly if the worst-case scenarios materialise.

5.2.4 Contingency Analysis

The contingency analysis capability of the CAS will support all three of the user groups listed above. The architectural elements covered in the high-level architecture illustrate its capability to generate and manage network models that support real-time operations and planning functions.

5.2.4.1 High Level Architecture

Fundamental to Contingency Analysis simulation is the creation of a ‘base case’, which is a model of the power system in its normal steady state operation. Within the KASM CAS, a real-time base case will be produced from PowerOn Fusion using the distribution power flow (DpF) extract capabilities, and this will be merged with a Common Information Model (CIM) extract from PowerFactory, a network planning tool for EHV networks at UKPN. The two models are joined as the real-time and connectivity data from the PowerOn Fusion is essential for getting an up-to-date view of the network and the asset characteristic data is required from PowerFactory, which is routinely used in power system modelling.

At present the data in each of these two systems (PowerOn Fusion and PowerFactory) exists in isolation. There is no automated reconciliation between the two systems and the data must be mapped from one system to the other.
The CAS will operate in three different modes – Real-time, Look-ahead and Study – to complement the different user roles defined in the previous sections. The overview of the system architecture is shown in Figure 5 below.

![System Architecture Diagram]

**Figure 5: A block diagram showing High Level Architecture for the CAS**

### 5.2.5 Network Control (Real-time Network Operation)

The expectation is that the CAS is a standalone application that sits alongside the DMS. The DMS has a live electrical model of the power system which can be exported for contingency analysis. The CAS will provide online network status, possible violations and the capability for control room engineers to run the application in Study mode to check the feasibility of suggested network configurations.

The source of the network model to generate the base case for the control room engineer will primarily be derived from the data in PowerOn Fusion. However, the data in PowerOn Fusion, requires supplemental data from PowerFactory, which includes: transformer vector group information, generator equipment rating and impedance data.

### 5.2.6 Power System Models

The electrical model of the power system needs to contain the following information:

1. Description of network assets on the network, e.g. transformers, circuit breakers, overhead lines etc.
2. Connectivity of the network assets, i.e. how the network components are connected
3. Real-time status of the network, i.e. voltage levels, active and reactive power flows, switch positions, transformer tap positions etc.
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The data architecture and data requirements are described in detail in section 5.3.

5.2.6.1 Network Definition

The boundary of the pilot area being used within the KASM area has been defined on the basis of a number of substations whose power flows are known to be challenging to analyse, and which are becoming increasingly influenced by renewable generation and by activity on the National Grid transmission network, such as flows on interconnectors and large plant outages.

Irrespective of the topographical area of the network being analysed now or in the future — whether the KASM pilot area, the wider SPN licence area or the whole NG transmission network with the SPN licence area embedded in it — the following technical boundaries will apply:

- Within a 33kV/11kV substation, the network model will terminate at the SCADA measurements on the 11kV feeders
- At an earthing transformer or auxiliary transformer, the network model will terminate at the primary side. The network model should represent the transformer as an impedance to earth
- On 33kV feeders which are leaving the topographical area, the network model will terminate at the 33kV circuit breaker associated with that feeder on the substation that is inside the topographical area
- On 132kV feeders which are leaving the topographical area, the network model will terminate at the 132kV circuit breaker associated with that feeder on the substation that is inside the topographical area
- On 400kV or 275kV feeders which are leaving the topographical area, the network model will terminate at the 400kV or the 275kV circuit breaker associated with that feeder on the substation that is inside the topographical area

5.2.6.2 Network Trace Options

The PowerOn Fusion model data is exported in XML data format. The XML file contains a network model which is based on an electrical trace from a set seed (starting) point. When the network configuration changes — through switching or a circuit breaker tripping — the network trace will either grow or shrink. The CAS takes the XML file and any other asset information and solves a load flow regardless of how big or small the network is on every export. Three different network trace options are available for controlling the extent of the trace with the power flow analysis tool:

1. **Current network** — the current network is a model of the live power system network in real-time. The network is traced from a seed component and will stop at every open point or when it encounters a component of the selected termination component type. Dead (not energised) areas of network will not be in the model. This network model can be extracted with meaningful network status information (e.g. SCADA data)
2. **Design state** — the design state of the network is the network in its normally switched state
3. **Scheduled network** — within power flow analysis it is possible to superimpose switching actions on top of the current network state to create a user-defined switched view of the network

Initially, due to the NG transmission network not being modelled in the current live system, the extent of the network model will be limited to a section of the EHV/HV (132kV/33kV/11kV) network. The model will be taken from a network trace from a circuit breaker at the Sellindge 132kV substation up to the in-feeds from the supergrid transformers on the transmission network, down to the circuit breakers on the 11kV bus bars. This trace will be expanded as confidence in the CA tool is gained and modelling of the NG transmission assets is undertaken.
5.3 Data Architecture

5.3.1 Introduction

The CAS operates in three key modes – Real-time, Look-ahead and Study – utilising a mixture of static data, dynamic data and forecast data to build an accurate and converging (base case) model. The configuration and inputs of the model vary depending on the activated mode of the contingency analysis. Dynamic data reflects the current operating state of the power system and is updated in near real-time. Static data is updated by exception, representing elements such as display configurations/layout, and changes when the latter is modified or network components (transformers, lines etc.) are added.

The construction of an accurate model involves importing data from different sources for the creation of the base case scenario, which is essential to run contingency analysis. The base case scenario is a model of the power system in its normal steady-state operation. In order to create a (converging) power flow case for contingency analysis, the following information is required:

1. Network connectivity including switching status
2. Voltage level for the system
3. Line parameters (resistance (r), reactance (x), susceptance (b), rating)
4. Transformer parameters (r, x, rating)
5. Transformer tap changer parameters (side, ratio, angle, upper limit, lower limit or in another way tap position, high step and low step, neutral voltage and neutral position)
6. Shunt capacitor parameters (for those that will participate in control, their controlled bus and voltage schedule is required)
7. Load data (direction of power flow)
8. Generator data (Pmax, Pmin, Qmax, Qmin, voltage schedule and controlled bus)
9. Quad booster data (side, ratio, angle, upper limit, lower limit or in another way tap position, high step and low step, neutral voltage and neutral position)
10. Measurements (P, Q, Amps, V)

In addition to the data for the base power system model outlined above, the following data is required for executing and reporting contingency analysis:

1. Single line diagram of the power network
2. Forecast data for loads, wind generators and solar generators
3. Other additional information such as:
   a. Contingency list
   b. Monitoring list
   c. Capability curve (optional)
   d. Wind farm list
   e. Solar generator list
   f. Other renewable generator list
4. Project lookup tables which allow matches between the GE PowerOn name, the PowerFactory name and OSIsoft PI Historian tags
Figure 6 illustrates the CAS high-level data flow architecture and exhibits the internal and external data sources that feed into the CAS.

Figure 6: Block diagram showing the CAS high-level data flow architecture
5.3.2 Data Sources

Figure 7 shows the data architecture of the CAS in conjunction with the internal and external data sources required to support the various CAS operational modes, and also illustrates the internal and external data sources themselves. Internal data sources are internal to UKPN’s existing architecture. External data sources are external entities such as NG and the Met Office.

5.3.2.1 Internal Data Sources (UKPN Data Sources)

**DigSILENT PowerFactory**

DigSILENT PowerFactory is a power system analysis tool used by UKPN for outage planning and infrastructure planning. PowerFactory has a CIM export capability to extract the power system model and pass it to the CAS applications.

A full CIM export from PowerFactory is made available with all switches present, without network optimisation (i.e. no node reduction), so that the complete network is extracted for the on-line CAS. The equipment parameter data is copied from the CIM export file and matched, where possible, to the corresponding equipment in the GE PowerOn Fusion XML (PowerOn XML). The BSI Data Mapping Engine, running as a stand-alone application, performs the matching and stores the matched parameter data in the Parameter Matching table.

It should be noted that the CIM extract does not contain the transformer vector information that is required to create a full model for contingency analysis, even though the power flow solution in PowerFactory considers transformer vector groups. To obtain the required information, a PowerFactory-exported transformer data sheet (in Excel) is produced which the Data Mapping Engine then uses to match the vector group to the transformer windings.
GE PowerOn

GE PowerOn Fusion is UKPN’s Distribution Management System (DMS), which is used in the control room to manage the network in real-time. The DMS represents the ‘live’ running configuration of the network to the control engineers who manage the distribution network in real-time. The DMS receives SCADA data from Remote Terminal Units (RTUs) in the field and presents this data on a network diagram in the application. The DMS provides alerts based on user defined limits of equipment and also allows remote switching capability on the majority of the EHV/HV networks.

PowerOn Fusion is the source for the real-time network configuration and power flows on the distribution network which will be used in the CAS. PowerOn Fusion is also the source of the schematic diagram which will be presented in the CAS. The real-time network configuration and power flows will be provided through an export capability in PowerOn Fusion called Distribution Power Flow (DPF) trace, which provides the relevant data in a PowerOn XML export file with a proprietary format of a bus-branch power system model. The schematic diagram data will be provided by a separate export containing three files: a hot-spot-positions file, a connections file, and a world list file. These three data files are combined with data in the PowerOn XML file to produce the CAS single line diagram. The PowerOn XML export is supplied to the CAS on a configurable time interval, which was set at 15-minute intervals for the KASM project.

The file also contains the real-time network status data from the power system, which includes voltages (reported against busbars), current (reported against individual switches or circuit breakers), switch states, and tap positions.

OSIsoft PI Historian

OSIsoft PI Historian is the UKPN SCADA historian into which all available real-time data from the DMS is archived. Each network analogue has a PI tag associated with it, which provides the ID for retrieving the data from the PI database. For KASM, the PI database is used to extract historical load and generation data that is used to train the load and generation forecasting algorithms which sit within the BSI Forecasting Engine. The data from the PI database will be exported in Microsoft Excel format with measurement data recorded at half-hourly intervals. Once the forecasting algorithms have been initially trained, there will be no further interface between the forecasting engine and the PI database.

5.3.2.2 External Data (National Grid, Met Office ENTSO-E Data Sources)

NG Real-Time Data (NG Control Centre)

NG is the transmission network operator in the KASM network area. The CAS collects transmission network real-time control measurements data through the PowerOn XML extract. Real-time control measurements data is transmitted over an ICCP link that connects the UKPN and NG control rooms. ICCP data exchange details are explained in UKPN’s SDRC 9.1 report (Development of the strategy for Inter-Control Centre Communications Protocol for the purposes of KASM), which was submitted to Ofgem on 29 December 2015. The National Grid real-time control measurement information will be included in the PowerOn XML export, which is supplied to the CAS at 15-minute intervals.

NG Forecast Data

The CAS forecasting engine will receive NG’s wind generation forecast data. This forecast data includes 0-4 day ahead wind generation forecasts at an individual site level, and for sites larger than 100kW on an hourly basis. This data will be used as an input to the forecasting engine.

The Met Office

The Met Office is a national weather service provider in the UK. For the KASM project, the Met Office is the source of weather data including observational and forecast information. Weather forecast data will be periodically provided to UKPN by the Met Office via Excel files. The service will include a number of weather station sites which cover the geographic area of the KASM network. The data will be used to train the forecasting algorithms and as an input to the live forecasting engine.
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ENTSO-E

The CAS will take data from the ENTSO-E (European Network of Transmission System Operators for Electricity) Transparency Platform. This platform provides expected day-ahead power flows data across the European interconnectors. The data will be processed in the forecasting engine prior to being used in the Look-ahead (LA) Data Bridge and State Estimator. The data will include the expected power flows across the BritNed (1GW) interconnector and the France-Angleterre (IFA) interconnector (2GW). The forecast power flows are provided on an hourly basis.

5.3.2.3 KASM Data Sources

Custom Project Lookup Tables developed by KASM Team

The custom project lookup tables were developed by the KASM team to enable the mapping of PowerFactory CIM parameter data to the PowerOn XML extract and achieve matches by exception for equipment that did not correspond under normal processing. The following tables were defined and are used in the CAS:

- Parameter Matching table (csv)
- Generator lookup table (csv)
- Lines lookup table (csv)
- Rail load lookup table (csv)
- Site exception table (csv)
- Separate from the tables listed above, an offline contingency list table which is used to define the contingencies (csv)

Parameter Matching Table

The parameter matching stores the results of the matching process to define the relationship of the PowerOn equipment and the PowerFactory parameters. The output of this process is moved to the CAS folder area and will be used by the CAS Data Bridge to process each new PowerOn XML until this process is run again and the new table is substituted.

Lookup Tables

All of the lookup tables are text CSV-formatted files. These tables were developed and populated by the KASM team.

Supplemental List Files

These are text files which are supplied manually from offline sources.

In addition to the above, the BSI Forecasting Engine (which is part of the Contingency Analysis Suite) serves as a data source for forecasting data, using inputs from NG, the Met Office, ENTSO-E and data from the BSI Forecasting Engine. Details for each data source and its role in the overall Architecture are outlined in section 5.3.4.
5.3.3 Data Model Definition

Data from internal sources is essentially the distribution network model, circuit breaker statuses and analogue measurements. The distribution network model, circuit breaker status and analogue measurements are associated with various component types from different data sources. For example, the status of a switch and analogue measurements of that switch are captured within a switch component from PowerOn. However, the parameters associated with that switch will come from PowerFactory.

There are two types of data – dynamic and static – that are needed by the CAS for both online cases and planning study cases. Dynamic data is updated in near real-time to reflect the current operating state of the power system. Static data represents elements that are updated infrequently (e.g. display configurations/layout) and change when the latter is modified or network components are added.

5.3.4 Data Interfaces

The input data from the collection of data sources (as outlined in Figure 7) is supplied to the CAS, which in turn is passed through the Data Bridge, State Estimator, and Power Flow Solver module, and generates the contingency list, the monitoring list, and other supporting data that can be used in the Real-Time, Look-Ahead and Study modes.

At the start of the KASM project a State Estimation output was not available. Conventional contingency analysis solutions have a Data Bridge which uses the State Estimation as an input. The State Estimation used in the KASM project is based on the Distribution State Estimation developed by BSI during the project. The converted supporting files and the solved power flow case output together make a complete contingency analysis base case dataset, which is sent to the contingency analysis engines for analysis. This process develops case sets for both RT and LA CA Power System Models. In the following subsections, we detail the source of input data for each of the three contingency analysis engines used in CAS (Real-time, Look-ahead and Study).

5.3.4.1 Data Bridging and State Estimation – Real-time (RT) Mode

The data for the CAS-RT analysis is sourced from the PowerFactory CIM and the PowerOn XML extracts. Ideally, the source of the network model would be the PowerOn XML extract, which contains all of the static and dynamic data required to create a base case for contingency analysis. However, it was determined that the equipment parameter data in the GE PowerOn system was not suitable for the CAS. The resulting approach was to use the parameter data for these components from the PowerFactory CIM extract. The connectivity and line definitions will be taken from the PowerOn XML extract.

5.3.4.2 Data Bridging and Power Flow Solver – Look Ahead (LA) Mode

The base case in CAS-LA mode is generated using information from the Data Bridge and Power Flow Solver module. In addition, the forecast data for the load and generation sites, supplied by the BSI Forecasting Engine, is used to create the LA case (please see UKPN’s SDRC 9.3 report (Completion of installation of forecasting modules that will link the DNO control room with other data sources). This is an automatic process. The case is archived and the user can export the LA case to the KASM Study mode to run a full contingency analysis on the generated case.

5.3.4.3 Online Study Mode

The user has a choice of initialising the Study mode from either an online base case archived by the CAS or a planning case created in PowerFactory (a function to be made available in Release 1) and imported to the CAS Study mode as a CIM extract. A CAS study can be conducted on any one of three data sources:

1. An archived CAS RT case
2. An archived CAS LA case
3. A planning study case developed in PowerFactory
5.3.5  BSI Forecasting Engine

The BSI Forecasting Engine is a standalone application which sits within the Contingency Analysis Suite. It consumes:

- Metered data from the OSIsoft’s PI Historian database as an offline manual Excel file copy
- Met Office weather forecasts via FTP
- National Grid wind generation forecast
- ENTSO-E day-ahead interconnection schedules via FTP
- ‘Live feed’ measurement data from CAS

When the managed network footprint includes full or near full coverage of the forecaster and CAS snapshot data has been archived in the Forecaster database for more than six months, this historical data, provided by CAS, will be used to train and produce forecasts.

The BSI Forecasting Engine produces forecasts for the following:

- Load
- Wind generation
- Solar generation

Forecasting results are passed to the CAS Data Bridge for use in look-ahead analysis, and are made available to other UKPN applications through the BSI Forecasting Engine user interface.

For further details of the forecasting engine please refer to UKPN’s SDRC 9.3 report (Completion of installation of forecasting modules that will link the DNO control room with other data sources).

5.3.5.1  Network Diagram Change Process

The CAS updates for the single line diagram are processed under two scenarios. This is a manual process due to the low frequency of updates.

**Scenario 1: Complete update** (to be used when updating large portions of the system in CAS and when large scale changes to the network are made)

1. Generate a new single line diagram
2. Re-run data mapping process

**Scenario 2: Incremental update** (to be used when a small portion of the system is updated)

1. Update single line diagram (affected part only)
2. Manually update Parameter Matching table
5.4 Application Architecture

BSI’s CAS uses advanced power flow and smart Homotopy based power flow solvers\(^2\) to study the network for thermal, voltage and steady state violations due to a large set of contingencies. This implementation includes tailored data and application processing for UKPN’s existing online environment, to quickly assess the threat of varying power flows through grid supply points or from generators and to account for the impact of renewable energy.

A conventional CA Data Bridge uses state estimation as input. The Data Bridge generates a contingency list, or inputs and re-formats the externally-supplied contingency list to create monitoring lists and other supporting data that match the state estimation output. The combination of the converted supporting files and the state estimation output make a complete CA base case dataset, which is sent to CA engine for analysis.

In KASM, state estimation is not available from the existing power flow modelling applications and therefore a state estimation solution will be developed. Specifically, the Data Bridge will be enhanced to generate raw power flow base cases from a number of different data sources. This process is the main function of Data Bridge and Power Flow Solver for both the RT and LA modes.

The enhanced Data Bridge and State Estimator generates the CAS case set from various data sources and performs contingency analysis. The CAS Viewer receives results from the engine and displays them to the users. Through the CAS Viewer, operators can download an online case and launch Online Study Mode for detailed study and further contingency analysis. Furthermore, operators can initiate a dispatched (user-initialised) LA study by sending a request to the LA engine, which relays the request to the forecasting engine. Study Mode also accepts base cases generated directly from PowerFactory in CIM format, in addition to the archived RT and LA cases.

For both the RT and LA engines, there is a high availability solution which includes primary and backup servers. Both servers accept identical input streams, with each running independently of the other. Individual CAS Viewers are configured to utilise one of the server pairs as a primary server and the other as a backup server. If the primary server is out of operation, the viewers automatically and seamlessly switch to the backup server. The detailed architecture is illustrated in Figure 8 below.

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\(^2\) Solving power flow problems is essential for the reliable and efficient operation of a power network. Current software for solving these problems are typically based on the Newton-Raphson method and have several limitations. One key limitation is that a ‘good’ initial point is usually required to obtain a solution. Homotopy based techniques help to mitigate this limitation. The basic strategy to solve a system of non-linear equations using a Homotopy method is to start with a new system of non-linear equations which is easier to solve. Then, one constructs a family of problems through one or more parameters that are members of the system to be solved and the newly constructed system. Next, each solution of the new system is tracked towards the original system along the parameters to get the final solution.
Prior to online execution of CAS Data Bridge and State Estimator, the CAS Data Mapping Engine must be run using input from PowerOn and PowerFactory to associate common equipment that is represented in each of these third-party datasets. Each match creates an output record in the Parameter Matching lookup table, which associates the power system parameters from the PowerFactory CIM file with the matched equipment record in the PowerOn XML file. The Parameter Matching lookup table is subsequently used for internal processing in the CAS. Detailed data flow is discussed in the data architecture in section 5.3.
5.4.2 RT Data Bridge and State Estimator

The RT Data Bridge performs the following functions:

1. When starting, the RT/LA mode Data Bridge loads the converted static model data.
2. The Data Bridge automatically checks the folder where GE PowerOn exports the XML file, using basic file system functions. When a new dynamic network model data is available, the Data Bridge loads and processes the files. A raw RT base case is then generated.
3. The raw case is sent to the BSI simplified State Estimator; using the BSI RT Power Flow Solver, a power flow solution is generated.
4. The RT Data Bridge generates an RT dataset after combining the power flow solution, contingency list, monitoring list, capability curve, generator participation factor and other supplementary files.
5. The generated RT dataset is stored in the RT engine feed-in folder.

5.4.2.1 LA Data Bridge and Power Flow Solver

The LA Data Bridge performs the following functions:

1. The converted static model data is loaded.
2. The forecast folder is automatically checked for new forecast data and loaded.
3. After combining the forecast data with the current switching status, a raw LA base case is generated and the future network arrangement is scheduled.
4. The raw case is sent to the BSI LA Power Flow Solver to compute the LA power flow solution.
5. After combining the power flow result, contingency list, monitoring list, capability curve, generator participation factor and other supplementary files, an LA dataset is generated.
6. A mapping file is generated which consists of the hotspots file and the XML data and links devices in the bus-branch model with the components displayed in the single line diagram.
7. The generated LA dataset is stored in the LA engine feed-in folder.
8. The user dispatched forecast folder is checked for user dispatched forecast data. If user dispatched forecast data is available, user dispatched LA case sets are generated by following steps 3-5.
9. The generated user dispatch LA datasets are stored in the dispatch result folder.

The Data Bridge will not automatically update the static model data. Whenever there is a new static model, the user needs to stop and restart the Data Bridges by controlling relevant Windows Services. This is a manual process and has to be performed every time a static model is updated. It should be noted that the static model update frequency is low compared to the other data. The Forecast Engine and the Data Bridge share several folders through the CAS. Discrete folders and files are used for the applications in the LA thread to prevent file overwrite and file locks.

The LA Data Bridge and Power Flow Solver also provide the bridging between the LA Analysis and Control Engine and the Forecasting Engine. The data flow could be in either of two directions:

- LA Engine to the Forecast Engine: The live feed of measurement data is provided by the LA Engine. In the meantime, the LA Engine also provides the state estimation data to the Forecast Engine.
- Forecast Engine to LA Engine: In this direction, the Forecast Engine provides the forecasts (load, wind and solar generation) to the LA Engine.
Analysis and Control Engines

The Analysis and Control Engines are the heart of the CAS. They use the cases created by the Data Bridge and perform the contingency analysis. The Analysis and Control Engines run in the background in parallel computation mode in a periodic cycle.

A valid RT power flow solution is the key to the success of the project. Solving a raw power flow base case without knowing the voltage profile is a challenging task even for an offline planning application. In planning mode, convergence of a power flow often involves significant human intervention. Regular power flow could fail most of the time, especially when the system size is large. The online RT Solver has a higher requirement, in that it must automatically and continuously solve raw power flow cases generated from the RT Data Bridge at intervals of a few minutes, without any human involvement. A robust algorithm is a must for convergence of most of the raw base cases. In the CAS, we are applying a homotopy-based smart power flow solution algorithm developed by BSI, as the engine of the RT Power Flow Solver for best convergence results.

The main goal of the CAS is to identify violations on the network base case and the post-contingency case. There are normally three types of violations:

1. **Voltage limit violation** – this refers to voltage values at a certain bus that exceed its upper or lower limit
2. **Voltage deviation violation** – this refers to the condition where the difference between pre-contingency and post-contingency voltages exceed a defined limit
3. **Thermal violation** – this occurs when the current flowing through certain equipment exceeds the equipment limit

In addition to the above violations, voltage collapse is another condition that is identified by the CAS. Voltage collapse refers to a system instability where the power flow cannot solve due to the system conditions. During a contingency, voltage collapse may occur immediately if the post-contingency operating point does not exist, which is a serious condition in a power system.

Based on the existence of post-fault operation and violation, contingencies are classified as one of three types:

1. **Secure contingency** – this has a post-contingency operating point and no violation
2. **Critical contingency** – this has a post-contingency operating point and some voltage or thermal violation
3. **Insecure contingency** – this has no post-contingency operating point. An insecure contingency indicates that the system will not survive (no static solution) should the corresponding contingency occur. While the system may operate under certain violations for a certain period of time, the base-case power system will suffer from a voltage collapse immediately if an insecure contingency occurs. Conventionally, an insecure contingency is declared if the post-contingency power flow diverges.

The CAS engine can reliably identify insecure and critical contingencies after applying the base-case dataset against a list of credible contingencies. The outputs are three sub-lists:

- Secure contingencies
- Critical contingencies
- Insecure contingencies

For each of the above categories, the CAS provides a list of violations associated with each case. The results are archived automatically once the computation is done. Among the critical and insecure contingencies, the insecure contingencies are ranked as worst, followed by the critical contingencies. The critical contingencies themselves are ranked based on the severity of violations.
Contingency Analysis

The integrated method that has been developed for Contingency Analysis is described in the following steps:

1. Perform a power flow analysis on each contingency in the contingency list generated by the Data Bridge from steps 2-4. The contingency list is a pre-arranged/pre-defined list based on credible network outages defined by operational engineers.
2. If the power flow analysis diverges, perform homotopy-based Smart Power Flow to compute the margin to the voltage collapse point.
3. If the margin is less than one, declare it as an insecure contingency. Otherwise, export the post-contingency power flow when the margin hits one.
4. Compute violations. If violations exist, declare it as a critical contingency and export the violation list. Otherwise, declare it as a secure contingency.
5. Rank contingencies with the insecure ones at the top, then the critical ones and finally the secure ones. The limiting contingency is the most severe one.
6. If the limiting contingency is an insecure contingency, run preventative control. If the limiting contingency is a critical contingency, run corrective control. These terms are explained in Section 5.4.4.1 and Section 5.4.4.2.
7. Export the preventative and corrective control action recommendations.

5.4.4.1 Preventative Control

When the load margin to voltage collapse for the base case is sufficient, yet the system may still be insecure should certain critical contingencies occur, the integrated package determines effective preventative controls. These preventative controls are recommendations made by the CAS tool that the user should consider to secure the system. The preventative controls are implemented to increase the load margin for counteracting insecure contingencies by selecting controls from the following candidate options:

1. Transformer tap position using On-Load Tap Changer (OLTC)
2. Generator real power output
3. System reconfiguration

Additional details on the controls and related objectives are provided in the LADD, which is available upon request.

5.4.4.2 Corrective Control

Whenever there are violations, the integrated package determines effective corrective controls. These corrective controls are recommendations that the user should consider to secure the system. The CAS determines the corrective controls to remove violations by exercising all of the following control actions:

1. Transformer tap position using On-Load Tap Changer (OLTC)
2. Generator real power output
3. System reconfiguration

The results of the Contingency Analysis, along with the system file, are archived automatically and summaries of the results are written to the internal architecture reporting facility in .csv format.
KASM SDRC 9.2: Contingency Analysis System Integration

5.4.5 Online Study Mode

Study mode is the place for users to conduct detailed contingency studies of the network. Operators and engineers can run different analyses, and can manipulate system parameters to test their impact.

Study mode runs as a standalone process, which can be launched directly from the workstation desktop or from the CAS Viewer. In Study mode, the user can open an archived case from the CAS Viewer or load cases from local storage. Study mode can also load base cases generated from PowerFactory in CIM format and perform analysis on the case. When working this way, the wizard in Study mode will create a study case set based on the imported study case and other supporting files. Study mode has the same capabilities in terms of Contingency Analysis, Preventative Control and Corrective Control as described in section 5.4.3.

5.4.6 Forecasting Engine

The BSI Forecasting Engine is a standalone application. It utilises data from multiple data sources which are listed below and shown in Figure 7:

- Metered data from the OSIsoft’s PI Historian database as an offline manual Excel file copy
- Met Office weather forecasts via FTP
- National Grid wind generation forecast
- ENTSO-E day-ahead interconnection schedules via FTP
- ‘Live feed’ measurement data from CAS

When the managed network footprint includes full or near full coverage of the forecaster and CAS snapshot data has been archived in the Forecaster database for more than six months, the historical data provided by CAS will be used to train and produce forecasts. Initially, a data extract from the OSIsoft PI Historian database is used to train the forecaster algorithms.

For further details on forecasting application please refer to UKPN’s SDRC 9.3 report (Completion of installation of forecasting modules that will link the DNO control room with other data sources).
5.5 Technology Architecture

The technology architecture defines the landscape in which the CAS will reside. Communication interfaces, data storage and retrieval, linkage with other relevant systems, network and communication infrastructure to support the CAS are defined in this section.

5.5.1 Contingency Analysis Technical Design

Figure 9: CAS Cloud Architecture shows the Contingency Analysis architecture that will be delivered with the project. The architecture comprises the following components:

1. A high level view of the Technical Architecture
2. Servers to host the CAS
3. Contingency Analysis software
4. Data links to the source systems

The CAS solution has been designed to work with a Microsoft Azure cloud solution. There are a number of reasons why cloud based architecture has been chosen:

- Lower costs if using the server for short-term projects or if there are opportunities to power down the server outside core business hours. This concept is not viable when purchasing physical hardware
- Speed of deployment – it only takes around 15 minutes to provision a new server using a standard Microsoft image
- Ability to make configuration changes to virtual machine specification with only a reboot – very useful if there are any performance issues
- Scalability – as the project progresses, it is possible to add more virtual machines to a scalability set to increase performance, if the software allows this
- Moves UKPN closer to the Services Orientated Architecture (SOA)
- Reusability – any of the designed data items can be subscribed to by any future application or project within a small time frame. This will build our catalogue of data integration and make future data integration tasks faster and cheaper to implement. Rather than develop application-to-application interfaces, we have decoupled the business and integration logic.
5.5.1.1 Technology Architecture Components

Like other critical systems, the CAS is expected to operate in high availability configuration with primary and standby servers. Supporting IT architecture has also been designed for model, code and data migration from the development/test environment to the production environment.
Figure 10 shows the cloud based IT technology stack. Key components within this are:

- The use of Citrix XenApp to deploy the CAS client, which reduces the overhead from an IT operations perspective when it comes to software installation/upgrades and also removes the risk of installing software onto our secure control room workstations
- The high availability configuration, which uses the availability sets within Microsoft Azure
- The Azure Service Bus, which acts as the pathway for all data integration from our on-premise assets to our cloud presence
- Express Route, which provides a secure and direct connection between UKPN’s data centre and the cloud so that no data is transmitted across the public internet
- The scalability of the virtual servers – it will be possible to add more resources to a virtual server if it is seen to have any performance issues
KASM SDRC 9.2: Contingency Analysis System Integration

Figure 11 shows the existing IT infrastructure which UKPN already has in place. The key assets are the PowerOn Fusion and PowerFactory applications (the source systems for elements of the data required by CAS) and IBM Integration Bus and IBM Data Power (which forms the pathway for all data transfers into the CAS).

![Figure 11: A simplified outline diagram showing UKPN infrastructure](image)

The CA architecture will comprise the following hardware/software stack:

<table>
<thead>
<tr>
<th>System</th>
<th>Technology Component (Version)</th>
<th>Explanatory Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azure</td>
<td>Azure Service Bus</td>
<td>Cloud service supporting application integration via messaging</td>
</tr>
<tr>
<td>Azure</td>
<td>IaaS Virtual Machine</td>
<td>Infrastructure as a Service Virtual Machine</td>
</tr>
<tr>
<td>Azure</td>
<td>RemoteApp</td>
<td>Cloud based application hosting</td>
</tr>
<tr>
<td>IBM Integration Bus</td>
<td>Message Queue (MQ)</td>
<td>On-premise service supporting application integration via messaging</td>
</tr>
<tr>
<td>GE PowerOn Fusion</td>
<td>DPF Server</td>
<td>PowerOn Fusion is UKPN’s DMS and the DPF component carries out the bus branch network reduction and passes this output to CAS.</td>
</tr>
<tr>
<td>DlgSILENT PowerFactory</td>
<td>CIM export</td>
<td>PowerFactory is UKPN’s current power modelling tool and holds the loads, ratings and power flow models down to the 11kV circuits. This information is exported in Common Information Model (CIM) format, which is based on eXtensible Markup Language (XML).</td>
</tr>
<tr>
<td>ENTSO-E Transparency Platform</td>
<td>RESTful Data Service</td>
<td>The ENTSO-E Transparency Platform offers data relating to interconnect imports/exports. This is accessed via a RESTful web service and messages are in eXtensible Markup Language (XML) format.</td>
</tr>
<tr>
<td>Met Office</td>
<td>Met Office Data Feed</td>
<td>The Met Office data feed is a premium service, to which UKPN subscribes. The information is collected from the Met Office via File Transfer Protocol (FTP) and is in Comma Delimited Values (CSV) format.</td>
</tr>
<tr>
<td>Spazio</td>
<td>SFTP Server</td>
<td>Spazio is UKPN’s Secure File Transfer Protocol (SFTP) server.</td>
</tr>
</tbody>
</table>

Table 3: Hardware/software stack
5.5.1.2 Virtual Servers

The CAS is hosted on Microsoft Windows Virtual Machines, which in turn are hosted on the Azure cloud platform.

Based on the failover requirements, both for application stability and server availability, the virtual machines will run within two separate Azure availability sets. One set will hold the Real-time servers and the second will house the Look-ahead servers. By creating these availability sets we will have a 99.9% uptime Service Level Agreement (SLA) from Microsoft.

5.5.1.3 Scalability

The CAS architecture has been hosted on the Azure platform to allow for future scalability to include all three DNO areas. If UKPN expands KASM into new DNO regions, more virtual machines (or additional processing cores and memory, dependent on further cost analysis) will be added to deal with the processing of their respective DNO networks, as per BSI’s system requirements calculations.

5.5.1.4 Backup & Restore

All Azure storage is hosted on locally redundant storage across three separate virtual disks. Azure Backup will be added and can be scheduled to run backups daily or weekly and with locally redundant or geo redundant storage as required.

5.5.1.5 Performance

The expectation is that the chosen Azure platform will meet the performance requirements. However, hosting on the Azure platform gives flexibility in the processing power available and the underlying environment can easily be upgraded or downgraded as required.

5.5.1.6 Storage

The CAS application will be hosted on the respective virtual machines but there will be some storage provisioned within Azure Storage which will be used to archive data.

5.5.2 Application Software

The contingency analysis server will run on the Windows server virtual machines in the cloud.

5.5.3 Electrical Model and SLD

5.5.3.1 PowerOn Fusion

KASM is dependent on the PowerOn Fusion DPF server and the exports it provides. PowerOn Fusion runs the export on a scheduled basis via a scheduled job, which runs every 15 minutes. Once the export has been produced, the scheduled job transfers the output to IBM Integration Bus via the FTP, and the IBM Integration Bus then transfers the output file via SFTP to the Azure virtual machine, into the DPF directory. The CAS application then polls the specified directory and processes any new files on a timer basis.

5.5.3.2 PowerFactory

As changes to the PowerFactory model are quite infrequent, a notification will be sent to the PowerFactory administrator whenever a change to the KASM network area is detected from within PowerOn Fusion. Receipt of the notification will trigger a manual export of the electrical model, in CIM format, and this will be manually copied to the CAS server. The same notification method will then advise the CAS administrator to reload the model into the CAS application.
5.6 Security Architecture

The following section covers security considerations associated with the architecture design.

5.6.1 Physical

There are no requirements for the physical security of the CAS. The physical security inherited by the hosting infrastructure will meet any security concerns.

5.6.2 Communications

All external communications and links to third parties will leverage the existing corporate infrastructure and approved methods of communications:

1. SFTP using the Spazio service
2. HTTPS IIB gateway to ENTSO-E
3. FTP over VPN to NG

5.6.3 Information Security

The sensitivity of the data used within the CAS is low. The data originating from the NG Wind Generation Forecast interface could be considered to have some slight commercial value, however the data only provides a small subset of the generation forecast. Any transmission of data within corporate networks will utilise secure methods of transport, such as Message Queue (MQ), HTTPS or SFTP.

5.6.4 Existing Security Architecture Impact

The internal security architecture is already in place to support the secure transmission methods described earlier (MQ, HTTPS, SFTP), but there are some new requirements for the private cloud architecture. UKPN already has in place an Express Route link between our Data Centre and the Azure cloud environment for Microsoft Azure’s Infrastructure as a Service. However, in order to ensure the use of a private link for any internal service bus (IBM Integration Bus) to a cloud based service bus (Azure Service Bus), some changes will need to be made to the existing Express Route configuration/licensing to route Platform as a Service traffic down the same network route.
6 Architecture Sign-off

The purpose of the Architecture Review Board (ARB) within UKPN is to ensure that all IT Solution designs are:

- Strategically aligned
- Avoid high costs of development, operation and support
- Are of sufficient quality
- Minimise risks
- Demonstrate re-use and replication of existing solutions where appropriate

In the context of the KASM project, the role of the ARB was to review the CA integration design and provide the architectural assurance and guidance to the project.

The KASM CA integration architecture was presented to the ARB by the Project Architect. The main areas of focus for the submission were around how to transfer data and the hosting environment for KASM. The submission was approved with the key points being:

- The high-level solution architecture is appropriate
- The use of our existing Enterprise Service Bus (ESB) to transfer files/data across UKPN’s network
- The use of a new Azure Service Bus to transfer files/data within the Azure cloud network
- Using bus topics to ensure reusability of data feeds (where appropriate)
- The hosting of Azure on cloud based virtual servers
- Using the newly commissioned ExpressRoute network connection which provides UKPN with a dedicated path between our internal network and the Azure cloud. No use of internet networks in the transferral of data between UKPN and Azure cloud
- FTP to either MQP or AMQP as soon as possible in the transfer chain. Also ensures delivery and allows re-use of any of the data feeds for future use
7 Completion of Installation and Demonstration

The project has successfully installed and demonstrated the core functionality of the CAS. The scope of this section is to define the Testing Strategy for the CAS, and the forecasting capabilities of the software platform. It describes the approach to testing and the phases involved to fully demonstrate that the solution delivers the functionality using all aspects of the hardware and software required for the CAS. This strategy defines the purpose of each test phase and the roles and responsibilities of each stakeholder for the test to be successful, which includes defect, change and release management processes.

7.1 Testing Strategy

The following section provides a high-level breakdown of the Testing Strategy applied. The detailed strategy has been captured in the project Test Strategy document, which is available upon request.

The CAS is envisaged as a tool that will support near real-time operations once implemented. This vision for the CAS transforms it from being an innovative application to a business-as-usual solution soon after being trialled for the purposes of the KASM project. Given the rigour needed to implement a system for supporting a critical system, the testing of the CAS has been split into two releases. Each release will have factory and site acceptance tests conducted and documented.

- **Release 0 – Core Product**: during this release the core applications and their capabilities were tested. The key areas of focus were: data import, data accuracy from import and solution quality perspectives, core system interfaces, engine performance, manoeuvrability and system installation.

- **Release 1 – Final Product**: during this release the full CAS application will be tested end-to-end. Modifications and/or fixes coming out of Release 0 will be incorporated. The application user interface will be fully developed with the automated integration of various data interfaces and applications.

7.1.1 Testing Overview

The KASM CAS testing followed a risk based test approach which entails both static and dynamic testing:

- **Static testing** involved evaluating a source document such as Requirements or Acceptance Criteria without execution of a particular test script. Static testing occurs during reviews and walkthroughs of source (approved) documents such as KASM Requirements, test scripts execution results or Acceptance Criteria

- **Dynamic testing** involves evaluating an application or a service based on its behaviour during execution of a particular test script. Within dynamic testing, various factors such as operational capability, accuracy, business risk and performance criticality were analysed, so that a decision could be made on the test phases to perform and the amount of testing to be done.

7.1.2 Testing Process

The next section describes the key processes that were applied during testing. Any deviations from this process are documented and justified in the Test Strategy document.

A number of test phases were coordinated and managed by the nominated test lead and executed by relevant testing team(s). The test teams comprised resources from multiple organisations or external third party organisations. During the testing phases all identified defects were registered in a common defect log. The defect log was distributed by the test lead to all relevant parties and was discussed on a regular basis to prioritise, resolve, release, retest and close all defects. The defect log was maintained across all testing phases, to ensure that defects do not reappear during future test phases and for audit capability.
KASM SDRC 9.2: Contingency Analysis System Integration

The test phases, at a high level, are:

Release 0:
- Factory Acceptance Testing – the supplier’s own testing prior to installation
- Site Acceptance Testing – validating the installation functions as per the design

Release 1:
- Factory Acceptance Testing – the supplier’s own testing prior to installation
- Site Acceptance Testing – validating the installation functions as per the design
- Network Testing – validating the communication connectivity and its integrity
- System Integration Testing – validating the CAS software with imported data and live system information from NG and UKPN sites
- Business Continuity Testing – ensuring CAS and forecasting systems work if any part of the infrastructure malfunctions
- User Acceptance Testing – verification of CAS solution against existing output from systems
- Non Functional Testing – to validate server/application related functions like backup & restore, data storage, user access, penetration/security and scheduled housekeeping tasks
- Operational Acceptance Testing – validation of process(es) to support CAS in live production, including routine data imports
- Cutover Process Testing (CP/CPT) – a dress rehearsal to ensure smooth transition into live production
- Regression Testing – to ensure that no errors or problems have been introduced and existing unchanged areas of the application/service still function as they did prior to the changes

Additional detail on the test phases is provided in the LADD, which is available upon request.

7.1.3 Organisations Involved

The following organisations or departments provided input into the CAS testing:
- UKPN’s operations team, who are day-to-day users of the system (control room engineers, outage planners and infrastructure planners)
- UKPN’s KASM project team, who are responsible for delivering the KASM solution
- NG’s KASM project team, who are responsible for assisting in delivering the KASM solution
- BSI, who are delivering the CAS and forecasting solution
- Navigant Consulting Inc., who are involved with the test script development and test supervision

There are a variety of other supporting suppliers/installers who are not listed here to maintain clarity.

7.2 Test Approach

At the start of each testing phase, the test lead was responsible for producing a detailed test plan specifying the total scope of the testing to be undertaken.

All test cycles were owned by specific test teams and allocated to a specific individual within the team. That individual was responsible for the production of the test preparation and for conducting the test execution.
KASM CAS Environments

The core CAS environment shows the infrastructure installed at UKPN sites. The environment includes the communication infrastructure, data storage, application servers, human machine interfaces (HMIs) and connectivity to external entities (e.g. generation and weather interfaces) for forecasting. The CAS has three distinct integrated environments:

1. Test (virtual server on a UKPN site)
2. Pre-production (server hosted in the cloud)
3. Production (server hosted in the cloud)

Integrated components:

- PowerOn Fusion (Production) (Pre-Prod and Test was available if required)
- PowerFactory (Production)
- Secure File Transfer Protocol (SFTP) (to receive files from NG)
- IBM Integrated BUS (IIB) (this has a Test, Pre-Prod and Prod)
- Inter-Control Centre Communications Protocol (ICCP) (Production) (Pre-Prod and Test is available if required)
- Internet connections with ENTSO-E and the Met Office

Human Interface (HMI) connectivity:

- UKPN users and administrators used their existing laptops and/or desktops to connect directly to all three CAS environments. Each user had a distinct way of connecting to CAS Test, Pre-Prod or Production, ensuring that no confusion occurred when logging into CAS
- External stakeholders connected via VPN tunnel and/or predefined access methods as per UKPN’s Security policy

As a default, all three environments were integrated with the existing production systems. For example, UKPN’s PowerOn Fusion and PowerFactory production systems were integrated with the CAS Test, Pre-Prod and Production environments. However, where available, equivalent Test and Pre-Production systems were used.

For Release 0 testing, only the CAS Test environment was used and all interfaces were manually integrated. Thus any data required by CAS was dropped into appropriate locations manually.

7.3 Testing Phase Details

7.3.1 Test Phase Entry Criteria

Standard software testing procedures with rigorous controls have been deployed due to CAS supporting critical real-time operations. Figure 12 shows the relationship and dependency of the test phases and documentation produced during the planning and execution of the tests. The documents are captured in orange and the workflows are captured in red.
Figure 12: Flowchart showing the relationship and dependency of the test documentation

7.3.2 Testing Responsibility Matrix

Table 4 shows the major activities and the role that is responsible for performing, approving or supporting the testing activities. The RASCI chart defines responsibilities and interrelationships, normally for tasks or deliverables for the test phases. All of the test phases are described in detail in the LADD. Unit and System testing is totally at the discretion of the supplier.

The acronyms are:

- **R** (Responsible): those who do the work to achieve the task. There is at least one role with a participation type of ‘responsible’ – although others can be delegated to assist in the work
- **A** (Accountable): the individual ultimately answerable for the correct and thorough completion of the deliverable or task, and the individual who delegates the work to those responsible. In other words, an accountable individual must sign off on (approve) work that the responsible individual provides. There must be only one accountable individual specified for each task or deliverable
- **S** (Supports): those who are in a position to support the activity and the infrastructure
- **C** (Consulted): those whose opinions are sought (typically subject matter experts) and with whom there is two-way communication
- **I** (Informed): those who are kept up to date on progress, often only on completion of the task or deliverable, and with whom there is only one-way communication
7.4 Testing Metrics

All test phases have the ability to extract test metrics. These indicate the progress, status and level of testing that was performed during that test. The metrics allow the test lead to understand how results from certain tests may impact the overall test plan and ensure that any defects that are picked up are shared with the wider test team. Further information about the testing metrics can be found in the Test Strategy.

7.5 Defect Management

The Defect Management process covers finding a defect through to it being resolved. Defect Management was applied to all phases of testing, from static testing onwards, with defects being raised by the test team during acceptance tests.

7.6 Release Management

Release Management allows the project to track each deliverable throughout the project life cycle. As changes are inevitable, the project and BSI undertook version control of any change to the system. BSI releases included the reason explaining the change and uniquely identifying the change and/or defect identifier. This helped to manage and test changes to the system prior to going live. Each delivery was accompanied by a release note describing the above.
7.7 Assumptions

Based on the knowledge at the time the Test Strategy was prepared, the project assumptions are listed below. If an assumption is invalidated at a later date, the activities and estimates in the Project Plan will be adjusted accordingly.

- A Project Plan is in place to identify the resource effort required to undertake the testing outlined in the Test Strategy.
- Project resources are in place and available, including subject matter experts, technical experts, hardware, desks, PCs etc. (see entry and exit criteria section for further details).
- The delivery of environments is on time and has been successfully tested by the suppliers.
- All project requirements must have been reviewed, agreed and placed under configuration control.
- Test resources have been identified and made available.
- The test environment will be prepared and set up in advance of test execution, pipe cleaned and available for testing activities as per the stated entry and exit criteria.
- Changes to the project scope will be made through a release management process. These may result in some of the test scripts being reworked.
- The hardware and software are available to facilitate the test execution.
- There is sufficient availability of data and support from various teams.
7.8 Test Results

The following section provides the results from testing and demonstrations of the CAS. It is the basis for validating that the CAS has been installed successfully on UKPN’s IT systems, and that the relevant tests have been performed to ensure the core functionality can be proven. Following FAT and SAT the relevant exit reports were produced and signed off by the supplier, test lead and business lead. Certain tests have been marked as partially completed in the Release 0 stage. Core aspects of the test have been completed using the Release 0 solution, however additional Release 1 testing is required to validate the full test. Moving forward, these tests have been retained in the list to ensure they are tracked and re-tested along with Release 1 testing.

7.8.1 Release 0 Testing

The testing process for the KASM project involved the preparation of detailed test cases. The requirements were analysed and relevant test cases were documented. The test cases target key business functional areas:

- Project related tests (shown in red)
- Real-Time control related tests (shown in green)
- Infrastructure Planning tests (shown in pink)
- Outage Planning related tests (shown in blue)

The requirements were analysed by the relevant functional groups and test cases related to the relevant requirements were documented in detail. This process ensured coverage of the requirements from various functional perspectives and resulted in multiple test cases relating to a single requirement. A summary of the functionality tested under each functional group is covered in the following sections.

7.8.1.1 Project-related Tests

These are test cases related to the basic operations of the system from an operational perspective. The test cases defined within this category aim to ensure the software is able to:

- Import/load UKPN data
- Accept modifications to the data
- Export the required results
- Perform various tasks
- Archive and retrieve the cases
- Report results on screen and through printable methods
- Maneuouvre the user interface

7.8.1.2 Real-Time Control-related Tests

Test cases in this category focus on the real-time functionalities of the system. They aim to ensure the software is able to:

- Reflect the validation of variations in near real-time
- Execute CAS in Real-time mode at regular intervals and store the case
- Create contingency case with various network elements
- Provide real and reactive power balancing capability
- Import control limits from DMS into real-time case
- Adjust network element ratings in real-time
7.8.1.3 Infrastructure Planning Tests

Test cases in this category focus on the feasibility of using CAS as an effective tool for infrastructure planning. They aim to cover the following aspects:

- Data validation before execution
- Comparison of the power flow results with the XML power flows using historical data
- Creating contingency cases in Study mode consisting of combinations of network elements and run CAS
- Running Load Flow in CAS to balance load demand and generation demand based on slack bus dispatch (within an isolated region)
- Configuring ratings of circuit components

7.8.1.4 Outage Planning-related Tests

Test cases in this category focus on assessing the capability of CAS in the outage planning operations. They aim to test whether the CA solution is capable of:

- Operating in three distinct modes (using real-time data, historical data and forecast data)
- Modelling a contingency case consisting of combinations of network elements
- Running studies for pre-determined and configurable intervals
- Modelling load flow to balance load demand and generation demand as well as real and reactive power
- Importing components from DMS and manually amending different component ratings
- Using the network switch and reflecting the connectivity arrangements taken from the DMS system

Table 5 presents a summary of test outcomes.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Test Description</th>
<th>Success Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.2</td>
<td>Real-time performance of load flow and contingency analysis calculation</td>
<td>Y</td>
</tr>
<tr>
<td>3.1.3</td>
<td>Study mode performance of calculating load flows and contingency analysis</td>
<td>Y</td>
</tr>
<tr>
<td>3.1.4</td>
<td>CA Model management</td>
<td>Y</td>
</tr>
<tr>
<td>3.1.5</td>
<td>The CAS must provide data for outage management studies and analysis</td>
<td>Y</td>
</tr>
<tr>
<td>3.1.6</td>
<td>The CAS must provide data to support reliability management studies and analysis</td>
<td>Partial completion. Release 1 test required</td>
</tr>
<tr>
<td>3.1.8</td>
<td>Study cases and results</td>
<td>Partial completion. Release 1 test required</td>
</tr>
<tr>
<td>3.1.9</td>
<td>The outputs from the CAS shall be represented in a clear and concise format, supported by data tables and a single line diagram which can easily be interpreted – both in Study mode and Real-time mode</td>
<td>Partial completion. Release 1 test required</td>
</tr>
<tr>
<td>3.1.13</td>
<td>The CAS will be able to import the network model and its specifications from DigSILENT PowerFactory. The methods for integration must be robust, i.e. Common Information Model (CIM)</td>
<td>Y</td>
</tr>
<tr>
<td>3.1.14</td>
<td>The CAS model must be capable of taking detail networks and equivalent networks (400kV, 275kV, 132kV, 33kV, 11kV)</td>
<td>Y</td>
</tr>
<tr>
<td>3.1.15</td>
<td>The CAS must have flexible network model and allow for network updates based on changes in network detail and KASM network boundaries.</td>
<td>Y</td>
</tr>
<tr>
<td>3.1.16</td>
<td>The CAS must be able to exchange network models based on industry standard information exchange standards, i.e. Common Information Model (CIM)</td>
<td>Y</td>
</tr>
</tbody>
</table>
Table 5: Summary of Release 0 test results

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2.1</td>
<td>Validation of model variations are reflected in near real-time</td>
<td>Y</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Execute CAS in Real-time mode at regular intervals and store the case</td>
<td>Y</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Create contingency case with various network elements</td>
<td>Y</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Real and reactive power balancing capability</td>
<td>Y</td>
</tr>
<tr>
<td>3.2.5</td>
<td>Import control limits from DMS into real-time case</td>
<td>Y</td>
</tr>
<tr>
<td>3.2.6</td>
<td>Adjust network element ratings in real-time</td>
<td>Y</td>
</tr>
<tr>
<td>3.4.1</td>
<td>Data validation before execution</td>
<td>Y</td>
</tr>
<tr>
<td>3.4.2</td>
<td>Run CAS in Study mode using historical data and compare the power flow results with the XML power flows</td>
<td>Y</td>
</tr>
<tr>
<td>3.4.3</td>
<td>Create contingency cases in Study mode consisting of combinations of network elements and run CAS</td>
<td>Y</td>
</tr>
<tr>
<td>3.4.4</td>
<td>Run load flow in CAS to balance load demand and generation demand based on slack bus dispatch – within an isolated region</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.1</td>
<td>The CAS must be able to operate in three distinct modes</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.3</td>
<td>Run studies for pre-determined and configurable time intervals</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.5</td>
<td>Model Load Flow to balance load demand and generation demand</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.6</td>
<td>Balancing real and reactive power</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.7</td>
<td>Import components from DMS</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.9</td>
<td>Import different component ratings</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.10</td>
<td>Network switch status should reflect the connectivity arrangements taken from DMS system</td>
<td>Y</td>
</tr>
<tr>
<td>3.5.11</td>
<td>Data validations before execution of Load Flow calculations</td>
<td>Y</td>
</tr>
</tbody>
</table>

From Table 5 it is clear that the core functionality has been tested with successful results. These results are discussed in section 7.8.2

7.8.2 Results of Testing

As previously mentioned, the aims of the Release 0 testing were to ensure that the core functionality of the CAS was developed, highlight any concerns with data imports and validate the accuracy of the outcomes. This section explains the outcomes of key tests to demonstrate key CAS functionality – with the understanding that not all tests will be covered.

CAS is a supporting tool that will enhance real-time and planning operations to produce credible results. To ensure the data imported is accurate, several test cases were defined to validate the data import into CAS. For these test cases, a series of PowerOn network measurement data, time variant with multiple network changes, was imported into the CAS.

7.8.2.1 Data Import into CAS

The data import process involves utilising data from various sources; these have been explained in detail in the Data Architecture section. The key data imports that need to be performed in order to have a functioning model on which the CAS tool can perform analysis are the PowerFactory CIM data and the PowerOn Fusion XML data. In this section the tests related to data loading are performed.

The following screenshots illustrate the data loading from PowerFactory and PowerOn Fusion. Here, the related PowerFactory and PowerOn Fusion files are selected into the data mapping tool of the CAS and processed to generate a static data model.
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Figure 13: Running data mapping shows the interface of the data mapping engine. The relevant PowerFactory CIM file and PowerOn Fusion XML file are loaded through this interface.

Figure 13: Running data mapping

Figure 14: Data mapping successful shows the successful mapping of the PowerOn Fusion and PowerFactory models. This forms the base network model that will be analysed using the CAS tool.

Figure 14: Data mapping successful
Figure 14: Data mapping successful

Figure 15 shows the CAS application real-time/online mode window with a previously loaded case. The following diagrams are screenshots of a new XML file being loaded.

Figure 15: CAS application real-time/online mode window
Figure 16 illustrates the processor loading that indicates the complex data mapping and XML loading process of the CAS tool. The four peaks in CPU usage demonstrate CAS processing a new XML.

Figure 17 illustrates that the selected XML is loaded and the CAS tool has performed the base case contingency analysis.
To ensure proper loading of the data, multiple XML files that were time variant were loaded into the CAS tool. The following diagrams illustrate the tests related to loading of data from different intervals and the comparison of the variation in the data within the case.
Figure 18 illustrates that the first XML file is being loaded into the CAS online application viewer.

Figure 18: CAS screenshot showing XML load in viewer

Figure 19 illustrates the loading of a second XML file extracted at a different time. The viewer indicates the loading of the second XML file.

Figure 19: Example CAS screenshot showing loading of second XML and verification in viewer

New XML loaded with different timestamp

CAS reflects latest XML model available
Figure 20 illustrates the comparison of the data from two cases with varying timestamps loaded into the CAS tool. The two cases loaded were KASM_2016-0824_13_00_09.xlsx and KASM_2016-08-24_13_30_08. The data from the relevant cases was exported and loaded into a comparison tool that highlights the variations in the data contained in the two cases. The comparison tool highlighted that the components within each of the models were consistent; therefore, the import methodology was considered robust and to have been successfully demonstrated. The results from both models (which were taken 30 minutes apart) show a very similar number (940 and 941) of state estimated results, indicating the same model components.

7.8.2.2 Performance of Load Flow Contingency Analysis Calculation in Real-time and Study Modes

Testing the performance of the application is key to ensuring the tool is usable and can perform the analysis in the expected time frames. Performance criteria were identified during the requirements stage, and this section illustrates the related testing that was conducted.
In Real-time mode, assuming an optimised network and appropriate hardware, calculations such as load flows and contingency analysis must not exceed 30 seconds. In Figure 21 and Figure 22 it can be clearly seen from the computation time that the cases load and solve in real-time within 30 seconds.
Similar to the above real-time/online case performance, in Study mode, assuming an optimised network and appropriate hardware, calculations such as load flows and contingency analysis must not exceed two minutes. Figure 23 and Figure 24 illustrate the ‘Study mode’ window used to test the performance of the CAS in Study mode.

**Figure 23:** CAS screenshot showing example execution timestamp before Study Mode run

**Figure 24:** CAS screenshot showing example execution timestamp after study mode execution
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In comparing the execution timestamps from Figure 23 and Figure 24, it can be seen that from launching a study mode to running a full power flow and ranking contingencies it took 105 seconds. It should be noted that most of this time was utilised in capturing screenshots rather than actual computation time. The engine performance is very fast – and well within the two-minute requirement.

7.8.2.3 Power Flow and State Estimation Solver

The core functionality of the CAS tool is the Power Flow and State Estimation Solver. The ability to process the network model and perform contingency analysis in real-time and offline studies is critical.

The following section demonstrates that the CAS State Estimation and Power Flow Solver results are considered to be accurate. The screenshots show the launch of a study session from Real-time mode, which will enable the user to interrogate the power flow results. The CAS power flow results have been compared with actual PowerOn measurement points to validate the accuracy of the tool.

Figure 25 shows the viewer in Real-time/online mode, from which the Study mode will be initiated. It shows how the user can select a specific study case to analyse.
Upon selection of the study case, the study mode is initiated to perform the analysis shown in Figure 26 below.

Figure 26: Study mode window

The results of the power flow are shown in Figure 27 below.

Figure 27: Base case Power Flow run
To illustrate the change in the topology represented in the CAS, it has been decided to select Canterbury South GT1 for an outage. This is achieved through a series of steps using the interactive interface of the CAS and creating a contingency. The resulting analysis (see Figure 28) shows the flows being reduced to 0.0 – indicating the outage of the network element.

![Contingency Analysis (Study Mode)](image)

**Figure 28: Power flow result indicating 0.0 flow through element selected for an outage**

In addition to the above test, a manual comparison of results from the CAS tool and PowerOn screenshots was performed. This resulted in the following outcomes, which are within an acceptable error tolerance:

- RICH CB405 PowerOn screenshot shows 10MW, CAS base case shows 12.3MW (delta 2.3MW)
- RICH CB605 PowerOn screenshot shows 3.3MW, CAS base case shows 4.1MW (delta 0.8MW)
- RICH CB805 PowerOn screenshot shows 2.9MW, CAS base case shows 0.0MW (delta -2.9MW)
- RICH CB505 PowerOn screenshots show 8MW, CAS base case shows 12MW (delta 4MW)
- SELL CB305 PowerOn screenshot shows 44.4MW, CAS base case shows 41.2MW (delta -3.2MW)
- SELL CB505 PowerOn screenshot shows 64.2MW, CAS base case shows 57.7MW (delta -6.5MW)
- CANTS CB505 PowerOn screenshot shows 6.5MW, CAS base case shows 9.4MW (delta -2.9MW)
- CANTS CB405 PowerOn screenshot shows 59.3MW, CAS base case shows 59.5MW (delta 0.2MW)
- CANTS CB205 PowerOn screenshot shows 10.2MW, CAS base case shows 12.4MW (delta 2.2MW)
- CANTS CB105 PowerOn screenshot shows 9.1MW, CAS base case shows 12.4MW (delta 3.3MW)

It should be noted that the PowerOn Fusion analogue values are based on CTs 800/1A with an error range of 2-3% (16–24Amps which equates to approx. 3.5–6MW at 132kV). Almost all of the results fit within this band. The exception is SELL CB505, which is 0.5MW outside the acceptable range. However, this is not considered critical from an end-user perspective.

Additional tests to cover the full set of test cases including demonstration of balancing capability, changing of control limits, changing of equipment ratings etc. were performed during Site Acceptance Testing. The detailed steps and screenshots have been captured in the test results.
One of the challenges of using the CAS was that a solved State Estimator solution does not exist. To solve this problem, BSI had to generate a State Estimator solution that was credible enough to support the real-time operations, outage and infrastructure planning groups. The process used to validate the results is illustrated in Figure 29. While this will be the validation process when both Release 0 and Release 1 are complete, intermediate validation was performed by comparing the power flows from the CAS and the power flows from PowerOn Fusion.

![Diagram of primary and secondary tests for validation](image_url)
8 Engagement with Stakeholders

Engagement with other DNOs took three forms:

- UKPN hosted a series of webinars with DNOs and other interested parties to discuss the project
- UKPN attended the LCNI Conference, presented the topic and gathered feedback from the audience
- UKPN engaged with a number of parties in recent discussions of Grid Code changes with the Grid Code Development Forum and the Grid Code Review Panel.

These are explained in more detail in the table below.

### 8.1 Engagement through Webinars

<table>
<thead>
<tr>
<th>WebEx</th>
<th>Topic</th>
<th>DNO/TNO</th>
<th>Details</th>
<th>Actions taken</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Integration of existing modelling tools</td>
<td>WPD</td>
<td>A basic PowerOn extract was carried out as part of the FALCON project. WPD is expecting that more advanced network model extracts (e.g. CIM) will be required in the near future.</td>
<td>The KASM team disseminated learning through SDRC report and/or bilateral meetings.</td>
</tr>
<tr>
<td></td>
<td>Data quality</td>
<td>NG</td>
<td>In addition to defining data cleansing rules and to identify bad data, UKPN should consider comparing the output from a State Estimator with SCADA points.</td>
<td>The CAS produced residual error results which compare state estimation results with measured data. Where large errors occur this can be investigated further by engineers</td>
</tr>
<tr>
<td></td>
<td>Sharing of Transmission network models between DNOs’ operational and long-term planning teams.</td>
<td>NPG</td>
<td>Similar to UKPN, NPG have unsuccessfully investigated the possibility of sharing the NG network model currently provided to DNOs’ outage planning teams (for operational purposes) with long-term planning teams. This is due to restrictions under the Grid Code.</td>
<td>UKPN successfully applied for a Grid Code change to allow long-term planners to access the same NG network models and operational planners</td>
</tr>
<tr>
<td></td>
<td>Sharing of DNO connected generation outputs with NG</td>
<td>NPG</td>
<td>NPG is currently sharing data with NG under Week 24 information. The data is being provided to NG under Section 105 of the Utilities Act.</td>
<td>UKPN is sharing DNO metering data associated with embedded generators with NG</td>
</tr>
<tr>
<td></td>
<td>Utilisation of Initial Physical Notifications (IPNs) and Maximum Export Limits (MELs) from CVA Generators</td>
<td>NG</td>
<td>The KASM team has considered the use of this information as part of its forecasting solution, but has concluded (following discussions with NG) that the information is not sufficiently accurate to add value.</td>
<td>The KASM team decided not to pursue this as part of the Grid Code change.</td>
</tr>
<tr>
<td></td>
<td>PowerOn Fusion State estimation</td>
<td>WPD/NPG</td>
<td>A design decision has been made not to use the PowerOn Fusion state estimation functionality.</td>
<td>UKPN provided information to DNOs supporting this decision.</td>
</tr>
</tbody>
</table>
8.2 Engagement through the LCNI Conference

**LCNI Conference 2015**

The KASM project team attended the LCNI Conference in 2015 and engaged with a number of DNOs and National Grid. The engagement during the conference was mainly focused on receiving feedback from DNOs and NG on:

- The considerations for ICCP
- The data exchange between DNOs and NG
- Load and generation forecasting

A number of challenges that were previously covered in the webinars were discussed and followed up on accordingly.

**LCNI Conference 2016**

The KASM team attended the LCNI Conference in 2016. Various media were used to disseminate the project learning, including presentation sessions, videos and single page overview flyers. During the presentation sessions a number of questions were asked. These included:

Q1) How can Contingency Analysis be used to help develop DSR schemes?
   A1) The team believes that having a library of historic real-time power flows will provide a significantly improved dataset to analyse and determine where DSR schemes could be most appropriate.

Q2) What is the speed of running through the contingencies?
   A2) Currently this is operating within a number of seconds.

Comments from the audience suggested that DNOs agree they need to move away from worst-case operating practices and manage the network closer to real-time in order to maximise asset capacity.

8.3 Engagement through the Grid Code Development Forum and Grid Code Review Panel

The project engaged with NG to determine the best approach for proposing a Grid Code change. The change proposed was to amend the Grid Code to allow long-term network planners to have access to the same NG network models as UKPN’s operational planners.

Initially, the project team presented with UKPN’s outage planners and infrastructure planners at the Grid Code Development Forum on 4 February 2016. This forum discussed early-stage proposals to amend the Grid Code, and the audience included a range of stakeholders from generation developers and suppliers to transmission network operators and other DNOs. There was strong interest in the project, and stakeholders provided feedback highlighting the importance of data sharing between NG and DNOs in a changing environment.

Following the meeting, it was agreed that the project team should take the proposal forward to the Grid Code Review Panel. The proposal was presented to the Grid Code Review Panel on 16 March 2016; the audience included representatives from NG, Ofgem and a number of other stakeholders. The proposal was subsequently approved by the Grid Code Review Panel and released for public consultation on 15 April 2016. The consultation was supported by WPD and did not receive any opposition. The Grid Code was amended on 28 July 2016, following approval by the Gas and Electricity Markets Authority (GEMA).
In conclusion, SDRC 9.2, related to CAS integration and testing, covers the aspects of the different architectures aligned to the TOGAF framework. The Business, Data, Application, Technology and Security architectures are covered in sufficient detail to illustrate the overall picture of the CAS. The test results obtained as part of the Release 0 testing indicate that the core functionality of CAS is adequately demonstrated. The test results shown in this document, combined with the detailed test results, prove that the data import, performance and accuracy of results are well within acceptable limits. The document also covers the testing strategy used to test the tool. The CAS is expected to be a critical application used to support operations and planning.

The following sections cover the key lessons learned from the project to date and key risks associated with implementation of similar projects.

### 9.1 Lessons Learned

Lessons learned have been tracked and recorded on the project including, through a workshop, discussions with key stakeholders (held 24 October 2016) to identify the main lessons learned from the project to date. The discussion was structured around areas where other DNOs implementing such projects should focus, that may impact the implementation of such systems. Four key themes were identified during the workshop: data, interface, testing and security.

#### Data

- The data required to build a real-time power flow may not be able to be sourced from one application; it may require an interface with several applications. These applications may not have the same unique IDs for the same assets, therefore data mapping may be required.
- The synchronisation of real-time data is key to producing accurate power flow results.
- When exporting data from PowerFactory, CIM was considered the most appropriate export format. It is important to consider that there are various forms of CIM which provide varying amounts of information. When exporting the CIM models it is important to configure the export accurately.

#### Interface

- Using an integration bus provides a more sustainable and reusable solution for delivering data. The data can be easily accessed by other projects which require the same data.
- Data can be exported from the PowerOn Fusion DMS using the DPF trace options, however there can be significant complexity in retrieving a full network model. Several trace options may need to be used to export the data.
- When exporting data through the DPF trace, the export files do not contain any single line diagram attributes. The single line diagram definitions were exported using alternative export capabilities. Re-creation of the single line diagram is time consuming and the change process needs to be managed and documented very clearly to ensure the CAS is up to date.

#### Testing

- Validation of a power flow solver requires access to another reliable power flow solver in order to validate outputs.
- Testing should be done with primary and backup sources available.
- Access to the tool early in the process, is key to defining the necessary and sufficient test scenarios and create the detailed testing steps. There should be a period between completing development and defining the test scenarios.
- With multiple data sources being used in the application it is critical that installation guides provide every detail required to set up the programme correctly.
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Security

- The interface with existing UKPN systems requires substantial security measures.
- User permissions should be set as per responsibilities, rather than giving generic access to everyone involved.
- Linking outputs/alerts from the CAS back into PowerOn Fusion requires significant development regarding security. This was not included as part of this project but has been highlighted as a potential future enhancement.
- Additional security conditions should be considered for a cloud based solution.

9.2 Identified Risks

This section explores the risks associated with the integration of Contingency Analysis software within a DNO environment. The lessons learned on the KASM project are strongly linked to risks which have been identified in the list below. These risks have been mitigated against in numerous ways for the purposes of the KASM project. However, for future implementation of similar solutions, the following risks need to be mitigated against appropriately, considering the DNO environment.

1. Interfacing with multiple data sources can create complex integration architecture that needs multiple data bridges in order to translate data between applications. Multiple data bridges are difficult to maintain when introducing new data sources. To mitigate against future issues with data bridging, the project has used a robust integration bus which provides a single translation platform which can be managed efficiently. It is important to maintain any translation tables within the integration bus and if input data formats change, the integration bus will not be able to translate the data. Bearing this in mind, it is important that any application interface has a clear change control process to determine if updates to the integration bus are required.

2. When adding new applications within critical business functions it is vital that clear training is provided to users to ensure they are fully capable of deriving benefit from the solution. The project will mitigate against this risk through thorough user training, user acceptance testing and easy to follow user guides. A practical example of change is that within the control room each control desk has four monitor screens which are fully utilised in current operation practices. Providing the new software will require one additional screen on the control desk. It is important that the positioning of the screen is carefully designed in collaboration with control room engineers. The project team will continue to liaise with control room engineers to mitigate against any ergonomic issues which may result in adding more screens to the control desk.

3. Hosting critical solutions in cloud infrastructure carries security risks (e.g. data breaches). However, any such threats can be minimised through thorough design of the Azure cloud architecture and detailed penetration testing prior to go-live.

4. Building a control room interface with external parties can introduce additional risks. The security and reliability of the control room applications can be jeopardised if external parties do not manage interfacing applications robustly. To mitigate against this, clear terms of security management have been agreed with NG, who are interfacing our DMS through the Inter-Control Centre Communication Protocol (ICCP) link.

5. Introducing new business processes can be daunting to existing employees, who are familiar with a single way of working. To ensure confidence is developed in the new business process, the project aims to trial the solution over an extended period, during which engineers can run existing processes in parallel with the innovation CAS process. This will provide significant benefits to the end user.

6. Maintaining up-to-date network models in the CAS is vital. If out-of-date models are utilised in a decision-making process, it can result in potentially hazardous consequences. To mitigate against this, the project has implemented secure change control processes which will maintain up-to-date network models.

The project will continue to monitor risks and update mitigation actions. This will be captured in future progress reports and future SDRC milestones.