Scottish & Southern Electricity Networks

LEAN Low Energy Automated Networks

Low Energy Automated Networks (LEAN)

SDRC 9.4 Initial Learning from Trial Installation and Integration

Scottish and Southern Electricity Networks (SSEN) is the trading name of Scottish and Southern Energy Power Distribution (SSEPD), the parent company of Southern Electricity Power Distribution (SEPD), Scottish Hydro Electricity Power Distribution (SHEPD) and Scottish Hydro Electricity Transmission. SEPD is the contracted delivery body for this LCNF Project.

Document Ownership

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Version Control

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1.0	27/09/2018	Sarah Rigby / Maciej Fila	Final version for submission following internal review and sign-off

SDRC Report Specification

Criterion 9.4 Initial Learning from Trial Installation and Integration	• Installation of appropriate equipment at multiple sites. • Appropriate learning captured from the installation and commissioning of equipment on site. • Details of the system communications and control functionality. • Initial results of the site performance.
Evidence	A report including lessons learnt on all aspects of the integration and subsequent challenges.
Date	27th September 2018

The LEAN project team sincerely acknowledge the crucial role of colleagues, consultants and contractors in progressing the project, and express their appreciation to all those who have supported and contributed to technology development and delivery of the trials.

Executive Summary

The Low Energy Automated Networks (LEAN) project has developed and applied Transformer Auto Stop Start (TASS) technology to reduce losses at 33/11kV primary substations.

The key principal of TASS is to switch off one of a number of transformers in a primary substation at times of low demand to avoid the fixed iron losses associated with that transformer - akin to turning off a car engine when the vehicle isn't driving anywhere.

The TASS system provides local, automated control within the substation to monitor the loading and control this switching, and to respond to SCADA alarms and status information from other network assets. In addition, commands incorporated into the Distribution Management System (DMS) provide the central network Control Room with information on the status of the system together with remote management capability.

The scheme design developed through the project provides a streamlined system for integration with existing assets to deliver the TASS functionality. The technology has been deployed in primary substations on the SEPD network, and has achieved energy savings of 10-13 MWh per trial site over the first twelve weeks of operation.

This report presents the technology developed and the work undertaken to install the system for trial on the network, in accordance with the Project Direction and to meet the requirements of SDRC 9.4.

As with many new technologies, the introduction of TASS is not purely focused on development of the equipment - in addition processes must be established to ensure that the business can apply and interact with the system to gain full value from the technology without compromising our priority to provide a safe and reliable supply of electricity to our customers.

Consequently, the considerations related to the deployment of TASS will have relevance to the introduction of a range of decentralised control systems and automation as the industry transitions to the world of DSO with increasingly dynamic operation of GB electricity networks.

An overview of the LEAN project and the context of this SDRC 9.4 report is given in **Section 1**.

Section 2 introduces the concept of using TASS to reduce technical losses.

Section 3 describes the activities undertaken to develop the TASS technology and implement the trial stages of the project.

➡ This summarises 'how' the trial was delivered, and is aimed at innovation teams and other stakeholders interested in the development of such technologies within the context of an innovation project.

Section 4 presents the system architecture and control algorithm designed to implement TASS, and describes the data exchanges and physical integration of the scheme with our existing assets and systems.

➡ This illustrates 'what' was developed through the project, and is aimed at those considering the application of TASS or similar systems on their own network areas, and those interested in creating systems to provide similar functionality.

Section 5 describes the installation and commissioning activities associated with the different aspects of the trial system.

➡ This details 'what' was done to deploy the technology, and again is aimed at those considering the deployment of TASS or similar systems on their own network areas.

Section 6 considers the factors relevant to the scalability of TASS for wider roll out and replicability of the system for deployment across other network areas.

➡ This section is aimed at those considering the implementation of TASS at scale across a given network, and identifies factors relevant to the development of similar technologies.

Section 7 summarises broader learning points and recommendations drawn from experience during different stages of technology development and trial delivery.

➡ These considerations are relevant to a range of stakeholders from across the industry who deliver or oversee projects to develop similar innovative technologies suitable for deployment across different networks, including DNOs, third party organisations and the regulator.

Section 8 assesses the performance of TASS at the two initial trial sites to date with regard to the automated switching activity seen, the associated reduction in losses, and the effect of TASS operation on existing assets.

The next steps for the project are set out in the concluding **Section 9**, and subject to continued successful operation, the system will be trialled for a period of 12 months.

Interested parties are very welcome to contact the LEAN project team with any enquiries via lean@sse.com.

Contents

Acronyms

ANT	Active Network Topology
API	Application Programming Interface
AVC	Automatic Voltage Control
CB	Circuit Breaker
CBA	Cost Benefit Analysis
CI	Customer Interruptions
CML	Customer Minutes Lost
CoP	Crossover Point for TASS
CPU	Central Processing Unit
CRN	Change Request Note
DGA	Dissolved Gas Analysis
DMS	Distribution Management System
DNO	Distribution Network Operator
DSO	Distribution System Operator
FAT	Factory Acceptance Testing
FPI	Fault Passage Indicator
HIL	Hardware in the Loop testing
HMI	Human Machine Interface
HVPR	High Voltage Protection Relay
IED	Intelligent Electronic Device
I/O	Input/Output ports
IPR	Intellectual Property Rights
LCNF	Low Carbon Networks Fund
LEAN	Low Energy Automated Networks
LED	Light Emitting Diode
LOA	Limitations of Access consent
LVPR	Low Voltage Protection Relay
NIA	Network Innovation Allowance
NIC	Network Innovation Competition
NMC	SSEN's Network Management Centre
PD	Partial Discharge
PLC	Programmable Logic Controller
PoW	Point on Wave switching
POWRA	Point of Work Risk Assessment
PPR	Project Progress Report
RMS	Risk Mitigation Strategy
RTS	SSEN's Real Time Systems team
RTU	Remote Terminal Unit
SAP	Senior Authorised Person
SCADA	Supervisory Control and Data Acquisition
SDRC	Successful Delivery Reward Criteria
SEPD	Southern Electric Power Distribution
SGAM	Smart Grid Architecture Model
SSEN	Scottish and Southern Electricity Networks
SWA	Steel Wire Armoured cable
TASS	Transformer Auto Stop Start
TX	Transformer
WP	Work Package

1 Introduction

1.1 Overview of LEAN

The Low Energy Automated Networks (LEAN) project aims to establish whether it is technically feasible and economically viable to implement the proposed energy efficiency methods at 33/11kV primary substations on the Southern Electric Power Distribution (SEPD) network. It is a £3.1m project supported by Ofgem's Low Carbon Networks Fund (LCNF).

The two methods considered within LEAN are:

- Transformer Auto Stop Start (TASS) - this is the automated switching out of one of the transformers in a primary substation at times of low demand to reduce energy losses
- Alternative Network Topology (ANT) - this would make use of existing 11 kV feeder automation where available to allow a TASS site to operate in parallel with an adjacent primary substation

Prior to developing and trialling these technologies, the first phase of the project assessed the costs, benefits and risks associated with their application.

Within this, the work to validate the business case for the technologies indicated that TASS may be suitable for implementation at around 430 primaries across the GB distribution network, providing an energy saving in the region of 1,185,000 MWh over 45 years, equating to around 467,000 tonnes of CO_2e. The cumulative discounted net benefit associated with this saving would be in the region of £18 million[1]. This work also concluded that it is not considered financially viable to deploy ANT with TASS[2].

Accordingly, the decision was taken to proceed with developing and demonstrating the TASS technology on the SEPD network[3].

[1] derived using Ofgem's RIIO-ED1 CBA figure for the value of losses and the 2016 Electricity GHG conversion factor and 2016 traded carbon price

[2] as reported in LEAN SDRC 9.2 'Business Case Validation', March 2016 - available via the ENA's Smarter Networks Portal www.smarternetworks.org/project/sset207-01/documents

[3] as reported in LEAN SDRC 9.3 'Phase Two Decision Point', July 2016 - available via the ENA's Smarter Networks Portal www.smarternetworks.org/project/sset207-01/documents

1.2 Project Structure

The project has three distinct phases:

Phase One comprised the development of a comprehensive understanding of the costs, benefits and risks associated with deployment of the LEAN technologies. The information obtained during this phase supported evaluation of the business case, and a methodology for undertaking Cost Benefit Analysis on a site by site basis was created.

Phase Two focuses on validation of the approach through deployment and demonstration of the technologies (TASS, with ANT where appropriate) at primary substations selected to be representative of SEPD and GB distribution network scenarios, but also ensuring that there is minimal risk of supply interruptions.

Phase Three encompasses monitoring of the transformers at the substations selected for LEAN deployment over the operational period to capture learning relevant to the use of these technologies.

A Decision Point was incorporated into the project plan to ensure that there was value in proceeding from Phase One to the trial stages. To inform this decision, the findings from Phase One and the conclusions regarding the business case for the technologies were presented to both internal and external stakeholders, including GB DNOs. The responses received through this consultation supported SEPD's decision to continue the project and develop the TASS technology for trial on the SEPD network.

1.3 Overview of SDRC 9.4

This report presents the work undertaken to develop, integrate and deploy the TASS technology in line with Phase Two and Phase Three of the LEAN project.

The development of TASS builds on the initial work completed in Phase One, with additional detailed analysis and requirements capture carried out during delivery of these trial phases.

The Successful Delivery Reward Criteria (SDRC) are defined in the LEAN Project Direction. The key topics presented within this report, in accordance with the SDRC 9.4 evidence requirements, are as follows:

- Development of the TASS technology
- Installation and commissioning of trial equipment at SEPD sites
- Integration of the trial system communications and control functionality with existing assets
- Initial results from TASS operation at the trial sites

To provide the context for the scope of SDRC 9.4, the following additional SDRCs will be published over the course of the project as more experience is gained from trial operation:

- SDRC 9.5 'Monitoring & Analysis' - an appraisal of the techniques used to monitor transformer health, and assessment of any impacts on network assets due to TASS operation
- SDRC 9.6 'Site Performance to Date' - a detailed review of the losses savings achieved through deployment of the technology, and evaluation of both the benefits and potential impacts on asset health
- SDRC 9.7 'Network Losses Evaluation Tool' - refinement of the tool developed to allow DNOs to undertake a site by site cost benefit analysis on the deployment of the technology, reflecting experience gained from trial deployment
- SDRC 9.8 'Knowledge & Dissemination' - the project closedown report, including consideration of the deployment of the technology across the SEPD network if applicable

2 Reducing Losses Through TASS - Transformer Auto Stop Start

The minimisation of technical losses presents a challenge to network operators, however a reduction in losses contributes to a reduction in customers' bill, and the energy saving equates to a reduction in carbon emissions. These economic and environmental benefits highlight the importance of working to reduce losses, and as a condition of their Electricity Distribution Licence[4] all DNOs have an obligation to actively work to keep losses as low as reasonably practicable. To illustrate the causes of losses, two of our companion DNO organisations on the ENA's Technical Losses Task Group[5] have created helpful visuals which present the issues:

- Northern Powergrid have created a video introducing the concepts of fixed and variable losses on the distribution network, which can be watched here www.youtube.com/watch?v=M9v_2HDnMLI
- UK Power Networks have created an interactive diagram to explain the different ways in which energy is lost across the electricity system, and this can be found on their website here www.ukpowernetworks.co.uk/losses/#interactive

SSEN's LEAN project is focused on reducing losses from primary substations, and the key principle of TASS is to switch off one of a number of transformers in a substation at times of low demand to avoid the fixed losses associated with that transformer - akin to turning off a car engine when the vehicle isn't driving anywhere.

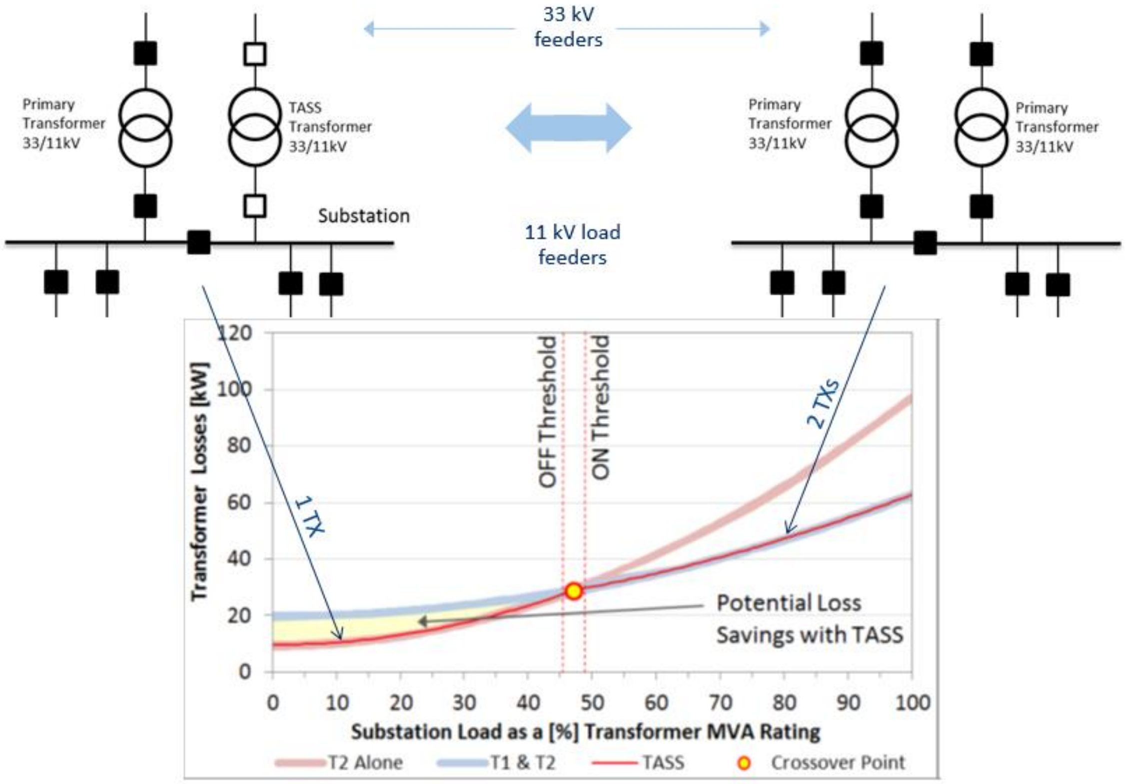
Relating this to the operation of a transformer, essentially the 'iron losses' from the magnetisation of the transformer core are fixed regardless of transformer loading, and 'copper losses' associated with the current flow increase with loading. It is therefore possible to save fixed losses by switching off a transformer at times of low demand, and these savings can be greater than the increase in on-load losses in the remaining transformer.

This principle is represented in Figure 1. The pink and blue lines represent the substation losses associated with running one and two transformers, and the red line indicates the principle of alternating between one or two transformers. The yellow dot is the crossover point, which is set specifically for each substation based on information about the transformers at the site and an assessment of their inherent losses, and the yellow area on the left reflects the saving in energy losses that can be made by switching to one transformer at times of low demand.

[4] a document setting out the standard conditions of the Electricity Distribution Licence is available via Ofgem's website www.ofgem.gov.uk/licences-industry-codes-and-standards/licences/licence-conditions

[5] more information on the work of the cross-industry Technical Losses Task Group can be found on the ENA website www.energynetworks.org/electricity/engineering/technical-losses.html

Figure 1 - TASS transformer switching principle - source S&C Electric Europe Ltd[6]



The concept was first proposed in the 1980's however at the time manual switching was required, with no automation available to respond to changes in demand or network issues. Advances in substation protection, communication, and monitoring and control technologies have allowed the LEAN project to develop and trial an approach that automatically controls this transformer switching in a safe, efficient and reliable manner.

Further, increasing levels of embedded generation and low carbon technologies such as electric vehicles, or behavioural changes influenced by the increasing deployment of smart meters or time of use tariffs, will influence the load patterns seen at some primary substations in time. Such changes to energy use patterns may result in some transformers spending a larger proportion of the year lightly loaded, or greater variations in the peak and low load demand levels, in which case the energy savings achievable through the deployment of TASS may significantly increase.

[6] 'LEAN Report', S&C Electric Europe Ltd, July 2015, prepared for SSEN during Phase One of the LEAN project

3 TASS Development & Trial Implementation

This section describes the activities undertaken to develop the TASS technology and implement the trial stages of the LEAN project, summarising 'how' the trial was delivered.

The content is aimed at innovation teams and other stakeholders interested in the development of such technologies within the context of an innovation project.

The work is presented under the following subsections:

Procurement
Risk Mitigation Strategy
Engagement with Colleagues
Trial Site Selection
System Architecture Development
TASS Algorithm Development
Incorporation of TASS into SCADA
Incorporation of TASS into the DMS
Substation and Transformer Condition Assessment Tests
Online Dissolved Gas Analysis (DGA) Monitoring
Installation & Commissioning Activities
Training
Management of Project Timeframes and Risk

Delivery of the TASS trials focused on both the development of the technology and consideration of how the business applies and interacts with the technology to gain full value from the system without compromising our priority to provide a safe and reliable supply of electricity to our customers.

Accordingly, the key project activities were as follows:

- Management of the procurement processes for the different elements of the trials, including selection of and engagement with suitable consultants, service providers and product vendors
- Engagement with relevant areas of the business to capture technical and functional requirements for TASS
- Selection of the trial sites and business approval for TASS application
- Creation of the Risk Mitigation Strategy governing the deployment of the technology
- Definition of the system architecture and creation of the specification for the TASS algorithm
- Programming and delivery of the TASS control device
- SCADA integration to provide the required data exchanges with existing substation assets and systems
- Incorporation of TASS status information and alarms together with TASS control commands into the Distribution Management System (DMS)
- Completion of a series of testing activities on the TASS control device and its integration with other system components
- Completion of a suite of transformer condition assessment tests and Partial Discharge (PD) surveys at the two initial trial sites
- Installation of online Dissolved Gas Analysis (DGA) monitoring systems at the two initial trial sites

- Installation and commissioning of the TASS system at the two initial trial sites
- Delivery of training sessions and briefings for operational staff, including field and control teams
- Coordinating the various activities associated with planning and implementing the trials, drawing on colleagues from across the business in addition to project consultants & contractors as necessary
- Activation of the scheme to commence the operational trials

Detail on the activities and deliverables associated with these tasks is given in the subsections below.

Procurement

The four work packages in Phase One of LEAN aimed to provide a clear understanding of the benefits, costs and risks associated with implementation of the proposed technology. In addition to assessing transformer losses and identifying potential risks to security of supply and network assets, a range of switching options and transformer energisation procedures that would ensure compliance with relevant codes and practices were evaluated. This work informed the development of a stepwise process for assessing the technical feasibility of TASS and ANT on a site specific basis. Correspondingly, a TASS Tool was created to provide a Cost Benefit Analysis (CBA) consistent with the RIIO-ED1 CBA approach[7], allowing the business case for deployment of the LEAN technologies to be refined. The work undertaken in Phase One is presented in SDRC 9.2 'Business Case Validation'[8].

The approach developed for delivery of the Phase Two and Phase Three stages of the project also assigned the requirements to discreet work packages, building on the four work packages of Phase One, as follows:

- Work Package 5 - Detailed Site Review for TASS Implementation
- Work Package 6 - Scheme Design for Each Selected Site
- Work Package 7 - TASS Platform
- Work Package 8 - Site Installation
- Work Package 9 - Site Sampling and Monitoring
- Work Package 10 - Decommissioning

The tendering and procurement process for these work packages was supported by the SSEN Procurement team, with a Scope of Works developed and issued to invite expressions of interest in one or more of the work packages from potential third party contractors and service providers. This Scope of Works can be found in Appendix A.

[7] as set out in Ofgem's 'Strategy Decision for RIIO-ED1 - Business Plans and Proportionate Treatment', March 2013 - available via the RIIO-ED1 Network Price Control section of Ofgem's website www.ofgem.gov.uk/publications-and-updates/strategy-decision-riio-ed1-overview

[8] LEAN SDRC 9.2 'Business Case Validation', March 2016 - available via the LEAN area of the ENA's Smarter Networks Portal www.smarternetworks.org/project/sset207-01/documents

A Smart Grid Architecture Model (SGAM)[9] was also created to communicate plans and project requirements, and support development of the systems to be implemented for the TASS trials.

SGAM is a three dimensional model that reflects principles applied in well established ICT architecture approaches for designing complex systems in a technology neutral manner. The SGAM framework encompasses all aspects of a smart grid system, from the electrical infrastructure and ICT technology to required information flows and defined functions. An introduction to SGAM and the initial model was provided in the LEAN Project Progress Report submitted in December 2016, and an overview of SGAM is provided in Appendix B of this report.

The TASS SGAM was used when engaging with third party service providers and product vendors during the procurement process, and an initial model was included in the Scope of Works to provide the context of the existing substation assets and communication systems. This model was subsequently evolved as further requirements were captured and the system design was refined. The resulting SGAM for TASS implementation is introduced in Section 4 'TASS System Design & Integration'.

A range of tender responses were received, and initial meetings held to discuss proposals and understand capabilities.

The preferred bidder for the site surveys (WP5), scheme design (WP6), TASS platform (WP7) and installation (WP8) stages was then identified based on knowledge and experience together with cost, and subsequently appointed.

To retain the ability to assess options and ensure suitability, the synchronising relays to be incorporated into the TASS scheme were procured directly by SSEN. The relay selected for use was Vizimax's SynchroTeq MVX unit, and prior to purchase one device was provided by the product vendor, UK distributor Enspec Power, on a trial basis to allow bench testing of the device's communication capability at SSEN's Protection laboratory. The project team coordinated this testing with Enspec and Schneider Electric, as the selected consultants for WPs 6 & 7, to ensure that the relays could be successfully integrated into the TASS scheme.

It became apparent that the site sampling and monitoring plans (WP9) comprised a number of activities that require different expertise and equipment, as such this work package was coordinated by the LEAN project team with the various specialist tests, monitoring requirements and site support being commissioned from suitable sources. Again, the SSEN Procurement team were engaged to ensure visibility and value throughout the procurement process.

Procurement for decommissioning (WP10) will commence as appropriate towards the end of the project.

[9] the TASS model has been created and evolved using the SGAM Visio Template developed through the DISCERN EU FP7 project www.discern.eu/project_output/finalreport.html

Risk Mitigation Strategy

As part of both communicating risks and guiding requirements capture, a detailed Risk Mitigation Strategy (RMS) was created to set out the measures being used to address safety, operational and data security risks associated with the trials.

The RMS provides detail on the operational principles and responses to different network situations designed into the TASS scheme, and sets out the roles and responsibilities of various teams across the business during the different stages of trial delivery.

Phase One of the project included identification of the key high level technical risks associated with deployment of TASS together with possible mitigation measures, for example from an operational perspective there is a need to carefully consider the potential for:

- customer interruptions and P2/6 compliance regarding Security of Supply
- power quality problems affecting customers or our assets and P28 compliance regarding Planning Limits for Voltage Fluctuations
- potential damage to assets

The RMS subsequently allowed us to identify a range of business specific safety and operational considerations and define detailed mitigation measures, which then shaped the design of the TASS scheme and underlie all of the principles built into its operation.

The RMS was enhanced and refined during the project, then finalised once details had been confirmed following testing and training activities. The final version of the document was signed-off by the Director of Engineering & Investment and other Senior Managers in May 2018. A copy of the RMS is provided as Appendix C.

In addition to the RMS developed for the TASS trials, a broader LEAN Risk Register has been maintained throughout the project in line with good project management practices.

This Risk Register is a live document designed to identify potential barriers to the satisfactory progress of the project. It provides a single log of risks as identified by the project team, and is used to develop mitigation and control measures and to target resources. It was created at project initiation and is reviewed on a regular basis, with any potentially significant risks raised with the Innovation Steering Board to ensure visibility and, if required, obtain support at that level for the implementation of any mitigation measures. The use of, and key changes to, this Risk Register have been reported in the Project Progress Reports.

Engagement with Colleagues

A high level of engagement with colleagues from across the business has been required in progressing the trial stages of the project. The primary aims of this engagement have been to ensure that all business requirements could be captured and incorporated into the project plans and scheme design, and to raise awareness of the project amongst key stakeholders as part of the process for communicating the identified risks and associated mitigation measures and eliciting support for the trials.

The teams engaged with include:

Protection	Strategic Investment
Real Time Systems	Substation Design
Operational Technology	System Planning
Cyber Risk & Information Security	Active Solutions
Business Assurance	Procurement
Network Management Centre	Training
Maintenance & Inspection	Regulation

Trial Site Selection

The selection of primary substation trial sites was in keeping with the stepwise assessment process developed during Phase One, though taking into account other factors associated with the trial nature of deployment, such as scheduled system planning and upgrade activities and timeframes for access to sites. A description of the stepwise approach can be found in SDRC 9.2 'Business Case Validation'.

Initially 11 potential sites were identified by the project team for more detailed consideration. These were chosen to be representative of typical primary substation configurations, and the identification of this number of potential sites was intended to mitigate against expected attrition in the number of sites suitable for trial installation within the project timeframes, or due to factors observed during detailed site surveys.

An additional 3 potential sites were suggested by colleagues from other areas of the business, including sites known to have a high level of solar photovoltaic (PV) generation and more variable demand profiles. These sites were proposed as future changes to transformer load patterns due to increasing levels of distributed generation or uptake of low carbon technologies, such as electric vehicles, may result in lower overall transformer utilisation factors which could increase the benefit of TASS in reducing losses.

Further information on these 14 sites was collated from various sources across the business, with key staff from a number of departments consulted to ensure the selected sites were suitable for trial operation. This information included such things as site configuration, protection schemes, potential CI/CML impact, and numbers of vulnerable customers. For reference and consideration by other DNOs with regard to their own innovation projects, the list of information gathered for this purpose is provided in Appendix D.

A detailed review of the information led to the creation of a shortlist of 8 sites to be taken forward to the site surveys undertaken as part of Work Package 5. The surveys on these shortlisted sites were completed between 20 April & 5 May 2017, with each visit attended by an SSEN innovation project engineer alongside Schneider Electric staff as the consultants engaged for this work package, to allow the suitability of the sites to be assessed and discussed. Observations and details from the site surveys are contained within Schneider Electric's 'LEAN Project Report'[10], provided in Appendix E.

In light of these surveys, two sites were selected, discussed and approved within the business for the trial deployment of TASS, with three additional sites identified and agreed for consideration as part of a subsequent round of installation should further deployment be merited.

The chosen sites allow consideration of factors common across SEPD primary substations, supporting development of a system suitable for application to a wide range of sites, including accommodating 2 to 4 transformers.

As the TASS trials involve the introduction of non-standard transformer operation with increased switching and energisation operations, this staged approach to deployment has been taken to ensure a minimal risk of supply interruptions should any significant issues with the TASS approach quickly become apparent, and to support cost effective project delivery by allowing any learning from the initial sites to be taken into consideration when planning further deployment.

As described in Section 9 'Conclusion & Next Steps', the decision to apply the technology at one or more additional trial sites will be taken once all aspects of the operation and performance of the TASS technology at the two initial sites are shown to be working satisfactorily, and in conjunction with SSEN's Innovation Steering Board.

[10] 'LEAN Project Report', Schneider Electric, September 2018

System Architecture Development

The architecture of the TASS system was established through Work Package 6 in collaboration with Schneider Electric as the consultants for this work. This addressed the hardware, functionality, and communication protocol requirements associated with the system's physical installation and integration with existing substation assets.

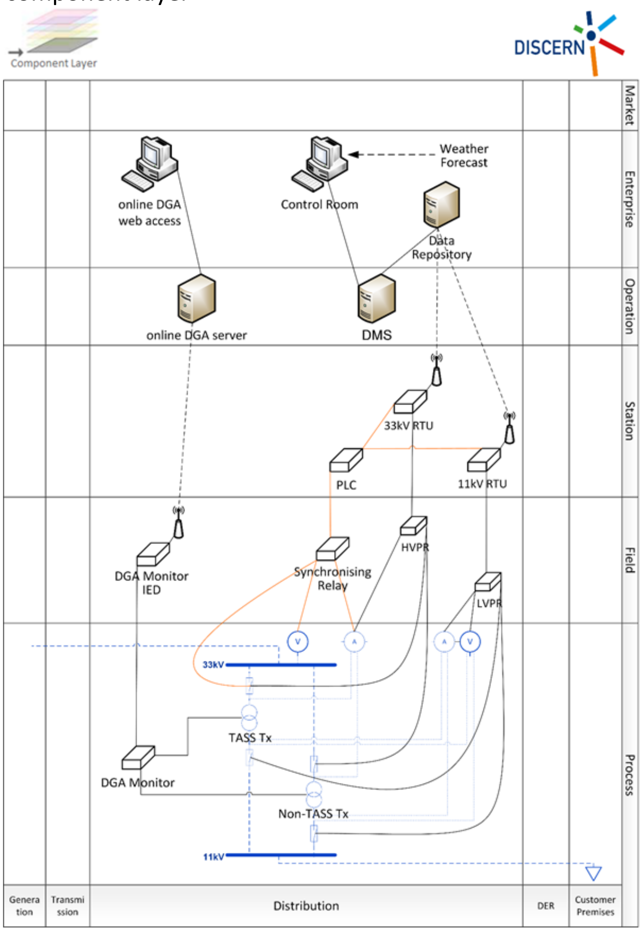
The key considerations for development of the architecture related both to the trial nature of the project and to the scalability and replicability of the system to support wider deployment of TASS should the technology be proven successful.

Accordingly, the requirements were to implement the scheme with minimal changes to the existing systems, and to have clear interfaces between our existing equipment and the trial kit. Similarly, a design was sought which could be widely applicable to a range of different substation configurations thereby requiring few, if any, changes to the architecture or information exchanged between devices at different sites.

From a functional perspective, the architecture needed to allow the TASS control device to take network data as inputs to the control algorithm. This includes substation loading data for the purpose of switching to reduce losses, in addition to alarms & status information from existing assets to identify any situation where it may not be possible or safe to initiate switching, in keeping with a fail safe design principle. It also had to allow the control device to issue signals to the existing protection relays to initiate switching of the circuit breakers. Additionally, a comms route with the central Control Room was required, allowing TASS specific status information together with remote command capability to be available to Control Engineers via the existing Distribution Management System (DMS).

The SGAM created for use in developing the system architecture was evolved as further requirements were captured and the system design was refined. This provides a technology neutral representation of the TASS system, including the components and their integration with existing assets, communications protocols, information exchanges, and functions associated with the different elements of the system. The SGAM image in Figure 2 shows the TASS Programmable Logic Controller (PLC) and synchronising relay components of the TASS architecture interfaced with the existing substation assets, including the transformers, protection relays (PR) and Remote Terminal Units (RTU) used for SCADA comms, in addition to the online Dissolved Gas Analysis (DGA) system used to monitor the transformers.

Figure 2 - TASS SGAM image - component layer



Device specific architecture proposals for the platform to be used as the TASS PLC and its integration with existing substation assets were developed by Schneider Electric. These illustrate how the chosen control device may be integrated with the three key substation configuration scenarios identified during the site surveys (i.e. one single RTU (Remote Terminal Unit), two local RTUs within the substation, and two remote RTUs), and are provided in Schneider Electric's 'LEAN Project Report'.

Detail on the architecture of the system developed is provided in Section 4 'TASS System Design & Integration'.

TASS Algorithm Development

The aim of the TASS algorithm is to provide the intended automated transformer switching functionality in a safe, efficient and reliable manner. Additionally, the TASS algorithm needs to ensure that security of supply and quality of supply are not compromised.

Consequently, the algorithm developed for the TASS trials provides local, automated control within a substation to monitor the loading and control this switching, and to respond to SCADA alarms and status information from other substation assets. In addition, the algorithm issues TASS specific notifications to the central Control Room via the DMS and enacts commands received from Control Engineers.

To ensure that TASS would not alter the operation of existing systems, full consideration of relevant standards, practices and day to day operation of the substation systems was maintained throughout development of the TASS algorithm. As described in the 'Risk Mitigation Strategy' and 'Engagement with Colleagues' subsections above, the project team also engaged with internal stakeholders including Protection, RTS, Operational and Control Room teams to obtain a clear understanding of all requirements, challenges, limitations and safety considerations. The Protection and RTS teams were also invited to review the proposed system architecture, and subsequently the testing activities included demonstration of the control device programmed with the TASS algorithm to both these teams to ensure their acceptance of the scheme.

To prepare for detailed development of the algorithm, an initial assessment of the equipment and considerations relevant to TASS system development was undertaken by Mott MacDonald within Phase One of the LEAN project, as reported in SDRC 9.2 'Business Case Validation'. This work reviewed the switching principles for 33 kV circuit breakers, equipment requirements, digital input and output signals, and analogue measurements identified as being key to the operation of TASS. In addition, fault levels and the protection and voltage control systems were evaluated to assess how best to integrate TASS within existing substation infrastructure.

Findings from this work together with additional investigation during Phase Two of the project were used to create the following specifications for development of the TASS algorithm, and ensure its compliance with all identified technical and functional requirements:

- TASS System and Algorithm Technical Specification
- TASS Algorithm Testing Specification

The resulting TASS algorithm and information on the testing undertaken to demonstrate satisfactory operation is presented in Section 4 'TASS System Design & Integration'.

The algorithm is implemented via the PLC control device shown in Figure 2 above, and Work Package 7 centred on the selection of a suitable platform for the TASS algorithm and development of the associated software code. The choice of platform together with a description of the processes used to apply the algorithm are also provided in Section 4.

Incorporation of TASS into SCADA

In addition to monitoring substation and transformer loading for the purpose of switching to reduce losses, the TASS PLC uses data from existing substation assets to identify any potential network problems. Information from a range of devices is required, however all necessary data is available via the existing SCADA system. To integrate TASS with SCADA, the TASS PLC connects to the existing communication RTU within the substation, with the required DNP3 data points mapped from the RTU configuration to the TASS PLC to ensure that all data is correctly interpreted.

The incorporation of TASS into SCADA for all associated data exchanges ensures that data security is maintained through the measures in place for securing our operational technology systems, in line with SSEN's Operational Technology Security and Risk Standard.

The TASS algorithm is designed to respond to the SCADA alarms and status indications in a manner that mitigates the risk of customer interruptions in the event that an alarm may be associated with the non-TASS transformer being about to fail whilst the TASS transformer is switched out. The principles applied are to return the substation to conventional operation where possible (i.e. with both transformers switched in and TASS operation halted), but to also avoid any operational risk associated with attempting to switch the TASS transformer back in onto a fault.

Section 4 'TASS System Design & Integration' details the specific SCADA data items used by the TASS system and describes the mapping process. Section 5 'TASS Installation & Commissioning' describes how SCADA integration was tested and proven during commissioning.

Incorporation of TASS into the DMS

To provide visibility of the TASS system to Control Engineers, system status information and alarms together with TASS specific control commands have been incorporated into SSEN's Distribution Management System (DMS), PowerOn Fusion, with data transfer and control via the existing SCADA system. This integration has been implemented in accordance with the business's procedures and work instructions for representing network alterations in the DMS.

The TASS status information indicates:

- whether the system is operational or has been deactivated remotely, via the DMS, or locally, via a local 'non-auto' switch in the substation
- when it's operating, and so is in the process of switching in or switching out a transformer
- how far the loading, or specifically amps, are away from the TASS crossover point, as a measure of whether it is likely that TASS will trigger switching in the near timeframe

Correspondingly, the alarms raised by the system are designed to flag an issue with TASS operation, or indicate that the system has identified a situation whereby it may not be possible or safe for the algorithm to initiate switching, including:

- TASS Failed to Operate - any event during which TASS operation fails while switching a transformer in or out, or where network data indicates that there may be an operational risk associated with attempting to switch a transformer
- TASS Faulty - an internal problem with the TASS PLC or an issue with its connectivity to substation or network asset data, such that the algorithm doesn't have all the input data required to make valid switching decisions
- TASS Crossover Point Error - any point when the TASS transformer is still switched out even though the load on the substation has increased above the TASS crossover point where both transformers should be in operation, in which case the TASS algorithm has not initiated transformer energisation as designed to do

If a TASS alarm is triggered, the Control Room can then review the situation taking into account other information shown in the DMS, and react accordingly, including restoring the TASS transformer if necessary.

The TASS commands support the Control Room in responding to operational incidents, and allow the substation to be returned to conventional operation at times of increased operational pressure, for example when a storm is expected. They also allow Control Engineers to remotely suspend TASS operation when someone wants to enter the substation, or if there are reports of a trespasser in the substation. This is important for safety, to minimise the risk of switching or transformer energisation whilst there is someone in the switch room or near the transformers.

Once any situation has been resolved and investigated if necessary, a Control Engineer can then re-enable TASS, and allow the system to resume automated control.

Section 4 'TASS System Design & Integration' provides detail on the operational principles and modes of operation built into TASS, and the design of the DMS user interface (UI) to support these. Section 5 'TASS Installation & Commissioning' describes how the DMS interface was tested and proven during commissioning.

Substation and Transformer Condition Assessment Tests

The site sampling and monitoring activities forming Work Package 9 were coordinated by the project team, with the various specialist tests and monitoring requirements commissioned from suitable sources.

The condition assessment methodologies used, as identified during the Phase One work, are described below. In addition to assessing current asset health, these provide a benchmark or 'finger print' of a transformer so that the same tests can be run during and/or after the TASS operational trials and compared to identify any changes.

- Oil sampling - a common approach for assessing transformer health through evaluation of the oil quality, including dialectic breakdown voltage and moisture level, and Dissolved Gas Analysis (DGA)
- Partial Discharge (PD) Analysis - partial discharge can be caused by mechanical, thermal or moisture issues with electrical equipment, and surveys are an effective tool for detecting potential issues
- Sweep Frequency Response Analysis (SFRA) - this technique assesses the mechanical integrity of transformers based on the understanding that the distributed RLC (resistance, inductance, capacitance) properties of a transformer are dependent on material properties and geometries - variations in SFRA results from a transformer at two different points in time will relate to variations in asset health
- Winding Resistance tests - used to detect faults with transformer windings (e.g. an open winding or shorted turn), and to verify the integrity of components such as the on-load tap changer
- Magnetising Current tests - used to detect defects in the magnetic core structure by assessing the current required to establish a flux in the core
- Winding Capacitance & Power Factor tests - used to assess the condition of the transformer insulation
- Capacitance readings - can indicate mechanical displacements of windings or partial breakdown in bushings, and power factor, also known as the dissipation factor or tangent delta, results can indicate degradation of the insulation or the ingress of water
- Dielectric Frequency Response (DFR) - estimates the moisture content of the transformer's solid insulation

Oil samples are routinely taken under business as usual, however, project specific oil samples were also taken at the trial sites. These results provide a reference point for comparison with future oil sample and DGA results.

The PD surveys were undertaken at the two sites in May 2017 by an SSEN colleague recognised as an expert in this area. The surveys indicated that the level of PD activity detected at the two sites represents a low risk of any issues.

Figure 3 shows a PD survey being undertaken on a transformer at one of the two initial trial sites.

Figure 3 - Photograph taken during a PD survey

The suite of other transformer condition assessment tests were completed at each site in October 2017. These were undertaken by transformer specialist consultancy Doble Engineering, and the results from these surveys suggested no indication of any problems with the transformers at that pre-TASS trial point in time. Figure 4 shows the testing underway on one of the trial transformers.

Figure 4 - Transformer condition assessment testing

Key findings from the substation and transformer condition assessment tests will be reported in detail in SDRC 9.5 'Monitoring & Analysis'.

Online Dissolved Gas Analysis (DGA) Monitoring

In addition to the point in time tests, an online DGA system will be used throughout the trial operational period to provide ongoing monitoring of transformer health.

This monitoring tracks oil sample readings on a day to day basis and will provide early indications of any issues, allowing investigations to be undertaken and the TASS trials to be halted if necessary. The intention is that any changes which may be due to TASS operation having an adverse effect on the transformers are identified prior to any incident, particularly a loss of supply event, occurring.

A review of available DGA systems was made and, with the support of the SSEN Procurement team, potential equipment/services suppliers were identified and contacted to ascertain capabilities with regard to multi-gas DGA and the provision of online data. Suppliers able to meet the defined project requirements were invited to provide quotes for equipment and service. The decision with regard to the preferred supplier was based on equipment functionality, support services, lead times and price.

The system selected for use during the TASS trials is Camlin Power's TOTUS Online DGA, and each transformer in the trial substations has been fitted with a DGA unit, as shown in Figure 5.

Figure 5 - Online DGA unit installed at a TASS trial site

DGA system site surveys at both trial substations were undertaken in July 2017. During these surveys measurements were taken of the top and bottom valves of the main transformer tanks, which are used to allow the flow of oil from the transformer tank, through the DGA unit for analysis, and back into the tank, and suitable locations for installation of the equipment were identified. The positioning of the units takes into account appropriate routes for the oil and power supply connections, and ensures that no access routes are obstructed and no operational hazards are created. The units were then installed during September 2017.

The system takes oil samples every few hours to give readings for the following 9 fault gases & moisture:

H_2 - Hydrogen	CO - Carbon Monoxide
CH_4 - Methane	CO_2 - Carbon Dioxide
C_2H_6 - Ethane	O_2 - Oxygen
C_2H_4 - Ethylene	N_2 - Nitrogen
C_2H_2 - Acetylene	H_2O - moisture

The data can be viewed by logging in to a secure system via a normal web browser, and in addition the system will send out alarms by text message and email if any readings rise above the thresholds that have been set, to immediately draw attention to any changes that may represent a possible issue.

As the system providing web access to the online DGA monitoring data is cloud hosted, a cloud server data security risk assessment was completed and the SSEN Solutions Integrity Group were engaged to approve use of the system, in accordance with the business's standard data security assurance processes. Where required, further details were obtained from the organisation providing the system to ensure vendor and system compliance with SSEN's Information Security Policy, Cloud Operating Standard, Third Party Standard and Operational Technology Security & Risk Standard.

Data obtained prior to commencing TASS operation provides a good period of pre-trial data which can be used for comparison with readings during the trial for the purposes of identifying and assessing any impacts on the transformers due to TASS, and for determining suitable alarm thresholds with consideration to potential seasonal variations.

The readings from this system can also be compared with results from conventional oil sampling to identify any differences and evaluate possible implications with regard to the assessment of transformer health through point in time oil sampling.

An illustration of the information provided by the online DGA system is given in Section 8 'Initial Assessment of TASS Performance at the Trial Sites', and the application of online DGA monitoring will be reviewed and reported in detail in SDRC 9.5 'Monitoring & Analysis'.

Installation & Commissioning Activities

This subsection provides an overview of the tasks and timeframes for installation and commissioning of the TASS system. Detail on the technical aspects of installation and commissioning, together with images showing the installed equipment, is given in Section 5 'TASS Installation & Commissioning'.

The wall boxes housing the TASS PLC were installed at the two initial trial substations - Hedge End & Gillingham - on 9 March 2018, with the comms connection implemented on 12 & 13 March 2018. Installation was undertaken by the consultants appointed for Work Package 8 under the supervision of the LEAN project team, with SSEN's RTS (Real Time Systems) team providing the comms connection into the existing RTUs.

Detailed commissioning plans were created for each site and subsequently reviewed and accepted by the Protection team and Control Room, in line with standard business approval processes.

The TASS system at Gillingham was subsequently fully commissioned on 4 April 2018 following a week of testing and commissioning activity, including its first live tests automatically switching out and restoring a transformer. Commissioning at Hedge End was completed on 29 May 2018, including installation and commissioning of the synchronising relays as DNP3 comms between the PLC and the synchronising relay had been successfully demonstrated at that point. Installation and commissioning of the synchronising relays at Gillingham was completed on 1 June 2018.

To allow the start of the trials to be clearly communicated to operational staff, TASS was fully activated at both sites on 8 June 2018.

Table 1 presents the resource requirements associated with the TASS trial installation and commissioning activity at the two sites. The experience gained from commissioning at the first site (Gillingham) significantly reduced the time required at the second site (Hedge End), and it can be expected that this would be further reduced should the technology be rolled out across the business, whether these activities are undertaken in house or using suitable, authorised contractors.

Table 1 - TASS trial installation & commissioning resource requirements

	Gillingham TASS installation & commissioning	Hedge End TASS & synch. relay installation & commissioning	Gillingham synch. relay installation & commissioning	Overall Total
no. days on site				
installation of TASS	0.5	0.5		
comms system connection	1	1		
commissioning of TASS	6			
installation of synch. relay and commissioning of TASS & synch. relay		4		
installation and commissioning of synch. relay			3	
	7.5	5.5	3	**16**
no. preparation days off site				
prep. of steel work & panel wiring for synch. relays		2	2	
		2	2	**4**
person days by resource				
Design Engineer	5	2	1	
Protection & Control Engineer	6	4	3	
SAP	6	4	3	
Fitter	1	4	2	
	18	14	9	**41**

New signage is displayed at the trial substations to inform staff of the presence of the TASS trial equipment and requirements for accessing the trial substations. Contact details for the Innovation project team and SSEN Control Room Emergency are also given on these signs. The signage has been created in accordance with the guidance set out in 'Safety Signs and Signals - Health and Safety (Safety Signs and Signals) Regulations 1996' and SSEN's 'Specification for the Supply of Signs, Notices and Labels'.

Location specific signs have been created for display on all substation access points and TASS trial equipment, as follows:

- TASS signage - A - access gates/control building entrance
- TASS signage - B - access to switchgear room
- TASS signage - C - TASS wall box
- TASS signage - D - control building exit
- Online DGA monitoring equipment

Figure 6 gives examples of the TASS signage.

Figure 6 - TASS signage

If the decision is taken to apply the technology at additional trial sites, the same installation and commissioning processes will be followed, with the same signage displayed.

Training

Safety, of course, underlies everything that we do, and whilst managing work in a live environment is core to SSEN's business, this automated switching may create an additional safety risk if there is someone near the switchgear or transformers when switching or energisation occurs.

Accordingly, training and briefings have been provided to relevant staff to provide awareness of the project trials, the new transformer operating arrangements and the requirements for working with the TASS system and accessing the trial substations.

The project team worked with senior managers from the associated Region and Network Management Centre (NMC) to identify the roles to be provided with specific training sessions or briefings via team managers as appropriate. It was agreed that training would be held for those whose roles will be most closely involved with the TASS trials, and that wider teams would be informed of the project and substation access requirements via their regular team briefings.

In addition, the RTS and Protection teams have operational roles that require staff to access primary substations, and indeed senior managers from both teams provided support during the development and deployment of TASS.

Table 2 shows the training and briefing requirements identified for the different operational roles.

Table 2 - TASS training & briefing requirements

	attend specific TASS training session	briefing via Team Managers/ Team Briefs
Regional Field Staff		
33kV authorised staff - e.g. 33kV Switchers, Fitters & SAPs	✓	
other authorised staff - e.g. 11kV Switchers, Fitters & SAPs		✓
non-authorised staff - e.g. Civils teams		✓
NMC Staff		
EHV Control Engineers (33kV & above)	✓	
other NMC staff - e.g. HV Control Engineers (11kV), Cartographers		✓
Other Operational Teams		
RTS team staff		✓
Protection team staff		✓

The individuals to attend the training sessions were nominated by their managers, and the SSEN Training team then scheduled the sessions and issued invitations to staff, in keeping with standard training activities. Due to the trial nature of the TASS technology, the training was delivered by the LEAN project team, however should the technology be rolled out to the business, it will be possible for the Training team to take on this role and use the material developed through the project.

A series of 10 sessions, specifically tailored to Field Staff or to Control Engineers, were run between 26 February and 27 March 2018, with some rescheduling of planned sessions required due to the adverse weather conditions and snow brought by the media named 'Beast from the East' and 'Storm Emma'.

The training was held at our regional depots (for Field Staff) & the NMC (for Control Engineers). Each session lasted 2-3 hours with typically 4-6 Field Staff or 1-3 Control Engineers in attendance according to the numbers of staff that could be released from operational duties at any one time. In total 22 Field Staff (33kV Senior Authorised Persons (SAPs), Fitters & Switchers) and 9 EHV Control Engineers attended the scheduled training sessions, with cascade training provided to those who were unable to attend on the day due to operational requirements.

All sessions were both interesting and engaging with a good level of interaction from attendees. As well as the project team delivering information about the trials, these events provided the opportunity for peer review from operational colleagues to verify the system design as created through the requirements capture stages.

A suite of material tailored to the different audiences was developed to support delivery of all elements of training and briefings.

The material created for the dedicated training sessions comprises slides, trainer notes, and a set of four handouts for staff to keep for reference, as described in Table 3.

Table 3 - TASS training material

training slide packs

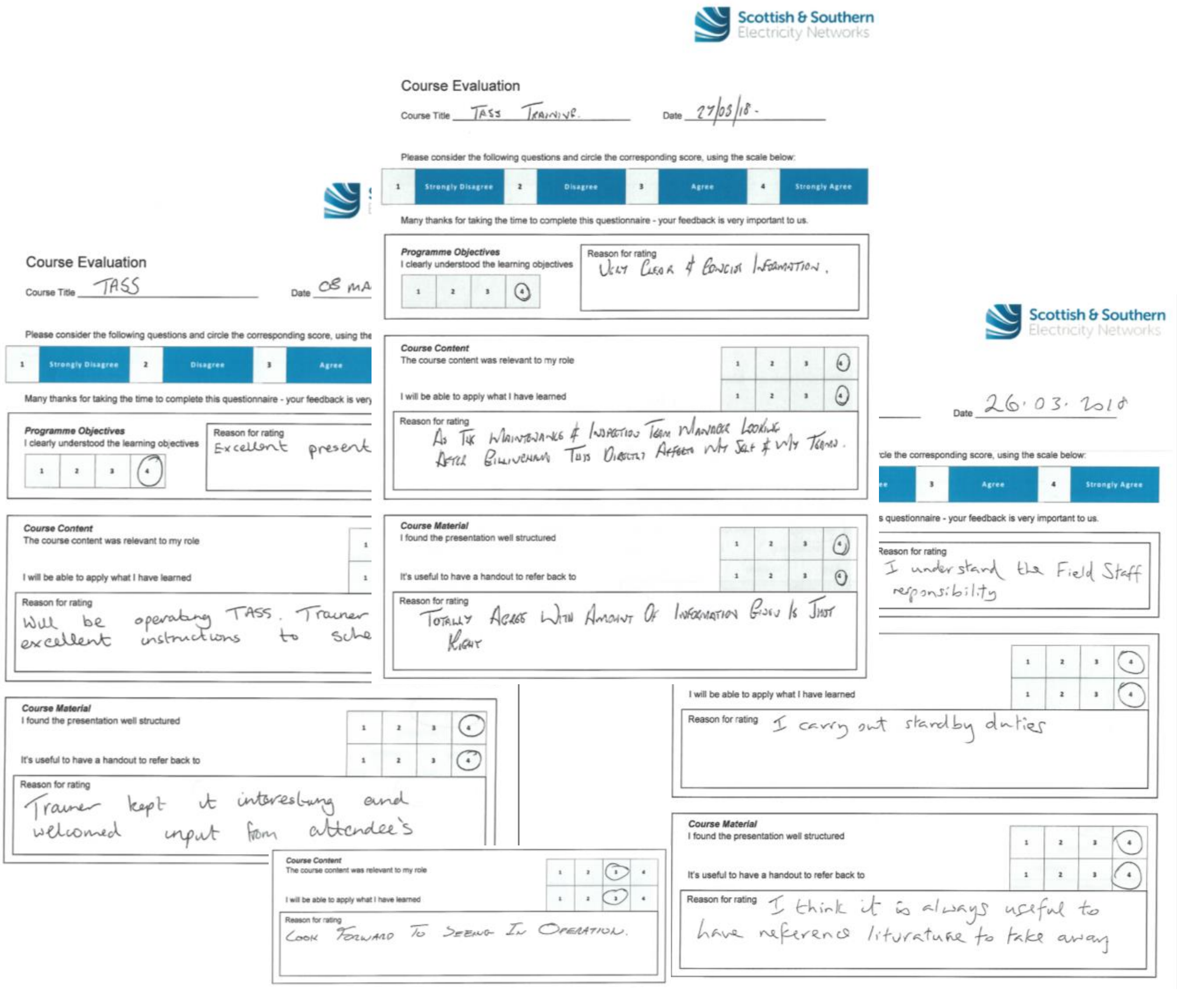
- TASS training material - Field Staff - 33kV authorisation
  a structured slide pack which introduces the TASS equipment and transformer operating arrangements; provides an understanding of the key principles relating to network operation and safety; details operational interaction with the system; and sets out the associated roles and requirements for 33kV authorised Field Staff
- TASS trainer notes - Field Staff - 33kV authorisation
  supporting notes for the trainer
- TASS training material - NMC - EHV Control Engineers
  a structured slide pack which introduces the TASS equipment and transformer operating arrangements; provides an understanding of the key principles relating to network operation and safety; details Control Room interaction with the system; and sets out the associated roles and requirements for EHV Control Engineers
- TASS trainer notes - NMC - EHV Control Engineers
  supporting notes for the trainer

Handouts

- TASS Field Staff Roles
  sets out the Field Staff roles relating to the TASS trials in a range of different situations, and in response to TASS specific alarms or statuses
- TASS NMC Roles
  sets out the NMC roles relating to the TASS trials in a range of different situations, and in response to TASS specific alarms or statuses
- TASS Operational Principles
  summarises the key operational principles designed into the TASS system, together with the reasons for adopting the chosen approaches
- TASS Reference Handout
  gives information on the trial plans, the project risks and mitigation measures, and the TASS system response to SCADA alarms & status information from other network assets

To make sure that the content was well pitched and covered information relevant to the individuals' roles, attendees were asked to complete training evaluation forms on an anonymous basis. Positive feedback was received both on the training and the TASS system, and some examples from the 31 evaluation forms received are shown in Figure 7.

Figure 7 - Examples from TASS Training evaluation forms



To facilitate the briefings given to the wider base of field and operational teams, briefing notes were provided to managers summarising the information to be covered, together with ‘take aways’ (a single A4 sheet) for staff to keep in their operational folders and refer back to.

In addition to the regional Field teams and NMC, briefing material was issued as relevant to the RTS and Protection team managers to support the briefings provided to their teams.

The suite of briefing material is described in Table 4.

Table 4 - TASS briefing material

briefing notes for Team Managers

- Briefing Note - authorised Field Staff
  informs Regional managers of everything to be covered for staff with switching authorisation (e.g. 11kV Switchers) regarding substation access, together with information on the purpose of the briefing, a summary of the TASS technology, and note regarding project timeframes
- Briefing Note - non-authorised Field Staff
  as above but with information applicable to non-switching staff (e.g. Civils team)
- Briefing Note - NMC
  informs NMC managers of everything to be covered with NMC staff who aren't EHV Control Engineers (e.g. HV Control Engineers, Cartographers) regarding substation access, together with information on the purpose of the briefing, a summary of the TASS technology, and note regarding project timeframes
- Briefing Note - RTS & Protection teams
  informs RTS and Protection team managers of everything to be covered for RTS and Protection staff regarding substation access, together with information on the purpose of the briefing, a summary of the TASS technology, and note regarding project timeframes

substation access 'take aways'

- SS Access take away - authorised Field Staff
  a ‘take away’ handout for staff with switching authorisation setting out the requirements for accessing a trial substation - including how to Pause TASS on-site if needed
- SS Access take away - non-authorised Field Staff
  as above but for non-authorised staff - including contact details for the 33kV authorised staff who’ve attended TASS training
- SS Access take away - NMC
  a ‘take away’ handout for non-EHV Control Engineers setting out the process to be followed when someone wishes to access a trial substation
- SS Access take away - RTS & Protection teams
  a ‘take away’ handout for staff with switching authorisation setting out the requirements for accessing a trial substation - including how to Pause TASS on-site if needed

All training and briefing material has been developed with consideration to future use should TASS be rolled out across the business, and in a way that will allow other DNOs to easily adapt it for their own use should they also want to implement TASS. Accordingly, this material will be available to other DNOs as an output from the LEAN project.

The suite of material is available on request by emailing the project team via lean@sse.com.

Management of Project Timeframes and Risk

In addition to the project delivery activities described above, the project team have maintained regular contact with Ofgem and the LEAN Project Officers to communicate project progress, both through scheduled conference calls and through the formal Project Progress Reports. Project timeframes have been regularly reviewed and assessed, with potential risks and impacts raised and discussed with Ofgem to verify that progress continued to be acceptable with regard to achieving the objectives of the project and fulfilling the SDRC deliverables set out in the Project Direction.

A key challenge early during trial delivery was in agreeing the terms of the contract to be put in place with the consultants selected for involvement in the development of the TASS technology, Schneider Electric. This included negotiation on the clauses relating to Intellectual Property Rights (IPR) and SSEN's need to ensure that these were compliant with LCNF requirements. Here, the proposed terms & conditions were issued to the consultants in April 2017, however it took a further 8 months to finalise the procurement agreement with their legal team and confirmation of approval was finally received in December 2017, allowing the Purchase Order to then be issued.

The principal challenges since the procurement contract was finalised were then in coordinating resources from across the business with many project activities running in parallel, in part reflecting the delays caused by that late signing of the procurement agreement, together with the need to reschedule some activities due to weather events affecting southern Britain in February and March 2018.

Concurrent to the contract negotiations, Ofgem had revised and reissued the Governance Document for the Electricity Network Innovation Competition (NIC), and in September 2017 confirmation was received from the Ofgem Project Officer for LEAN that their clarified definition of what constitutes a 'Material Change' under NIC project governance[11] has been adopted equally to LCNF projects, including the LEAN LCNF Tier 2 project. Section 8.23 of that governance document identifies a Material Change as including:

" • A change which alone or together with other changes delays the Project end date by more than one year;
- A change which alone or together with other changes delays the achievement of one or more Successful Delivery Reward Criteria by more than one year; "

Consequently, to allow us to create reports which draw on the right level of experience from the TASS trials, provide relevant learning for dissemination, and deliver value from project expenditure, a shift in the project timeframe and SDRC report submission dates was proposed and raised with Ofgem, as documented in the LEAN Project Progress Report from June 2018. Though the submission of reports would therefore be later than the dates contained within the Project Direction, they would still be well within the year which would otherwise constitute a Material Change

[11] the clarified definition of a Material Change requiring Ofgem's approval is provided in Appendix 1 and associated Section 8.23 of Ofgem's 'Electricity Network Innovation Competition Governance Document v.3.0', 30 June 2017

requiring formal approval from Ofgem in accordance with project governance. The significance and practicality of this for gaining learning from the project was discussed with Ofgem, and this proposal was accepted and implemented.

Notwithstanding the above, whilst the prolonged negotiation period limited how far the project could progress (for example equipment could not be purchased without a Purchase Order being in place, consequently no testing could commence), the LEAN project team continued to work on requirements capture from within the business, and with the consultants' engineering team regarding the specification and design of the TASS algorithm, to ensure that all aspects of the project would be well placed to progress as soon as the agreement was in place. This ongoing cooperation of Schneider Electric's engineering team was valued as it should be acknowledged that during that time they were working 'at risk' in the absence of the Purchase Order.

The project team have continued to closely manage project activities throughout delivery of the trial phases, and TASS was fully activated on 8 June 2018 to commence the operational trial period.

The key priorities throughout the project remain that everything is carried out safely, with all relevant staff and stakeholders informed, and that we can obtain the learning relevant to both meet the SDRC requirements and provide useful insight for SSEN and other DNOs and stakeholders. Ofgem's governance framework and this management of the project timeframes allows us to continue to be thorough on these aspects, rather than introduce compromises to meet a timeframe which has no material impact on the project.

4 TASS System Design & Integration

This section presents the system architecture and control algorithm designed to implement TASS, and gives detail on the data exchanges and physical integration of the scheme with our existing assets and systems.

This illustrates 'what' was developed through the project to deliver the TASS system, and is aimed at those considering the application of TASS or similar systems on their own network areas, and those interested in creating systems to provide similar functionality.

The system is described under the following subsections:

- TASS System Architecture
- TASS System Functionality
- TASS Algorithm
- TASS Algorithm Testing
- TASS Wall Box
- Integration of the Synchronising Relay
- TASS Integration with SCADA
- TASS Integration with the DMS

TASS System Architecture

The project team worked closely with Schneider Electric, as the consultants engaged for the associated work package, to develop the architecture of the scheme to be implemented and identify suitable components for TASS operation.

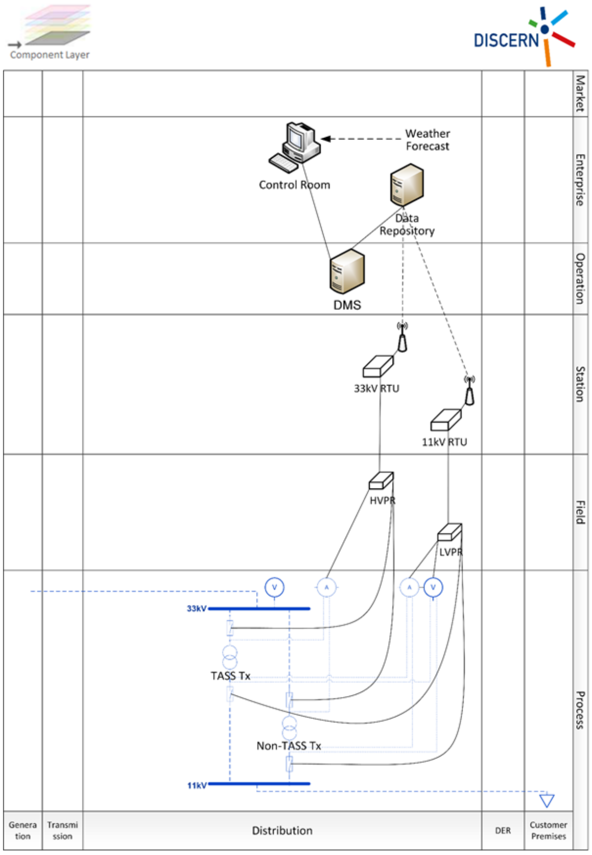
The architecture subsequently proposed for the trials has the TASS control device connected to the existing Remote Terminal Units (RTUs), allowing the normal operational and control functionality of the existing RTUs and protection relays to be retained without significant changes. Further, the architecture is suitable for integration with the three key substation configuration scenarios identified (one single RTU, two RTUs within the local area network, and two remote RTUs).

The four images in Figure 8 below show the component layer of the SGAM created to illustrate the architecture of the TASS system and its integration with existing assets[12]. All layers of the SGAM for TASS implementation are provided as Appendix B to show the communications protocols, information exchanges, and functions associated with the different elements of the system implemented.

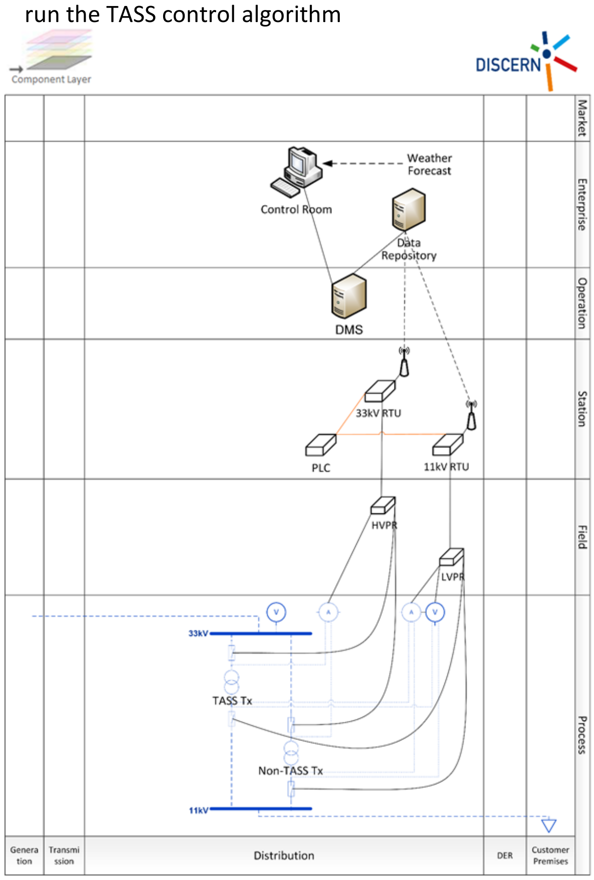
[12] the TASS model has been created and evolved using the SGAM Visio Template developed through the DISCERN EU FP7 project www.discern.eu/project_output/finalreport.html

Figure 8 - TASS SGAM images - component layer

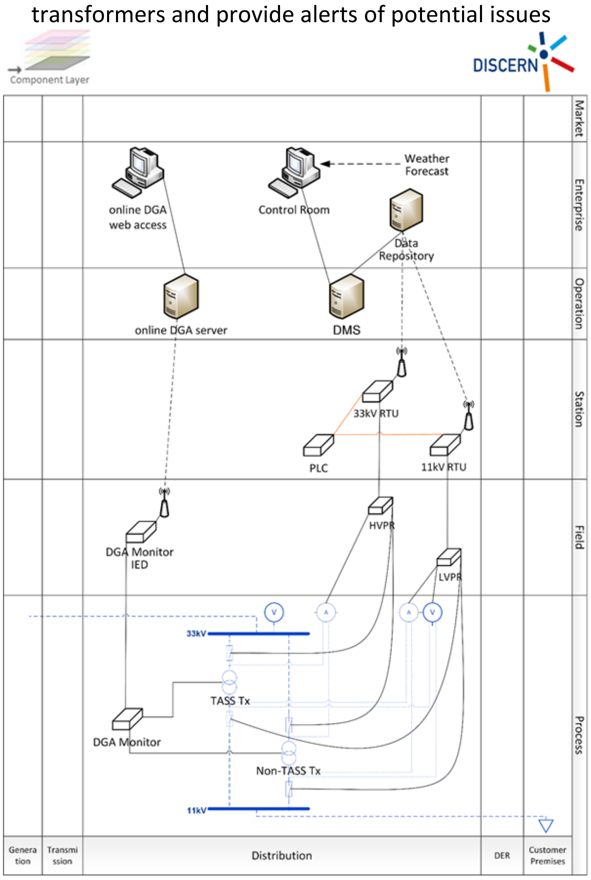
1) the existing substation assets



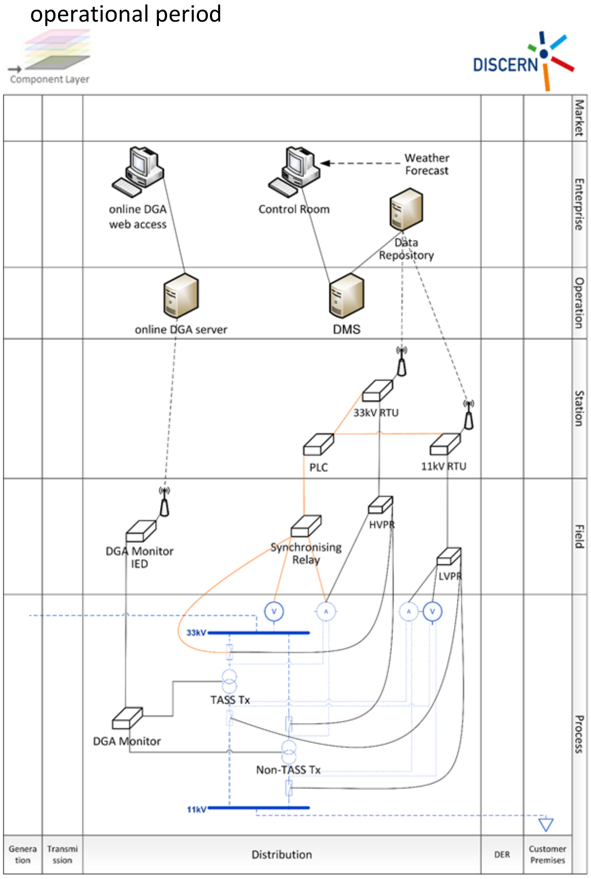
2) the TASS Programmable Logic Controller (PLC) will run the TASS control algorithm



3) the left hand side shows the online Dissolved Gas Analysis (DGA) system used to monitor the transformers and provide alerts of potential issues



4) synchronising relays providing Point on Wave switching will also be assessed during the trial operational period



The key item of equipment for the TASS system is the PLC control device programmed with the TASS control algorithm. This connects into the substation communication system via the existing RTUs to take network data as inputs to the control algorithm, and to issue control signals to the protection relays (PRs). This route also provides SCADA comms with the Control Room so that Control Engineers have visibility of the status of the TASS equipment, and are able to use the commands incorporated into the Distribution Management System to disable TASS and return the substation to conventional operation if someone wants to enter a substation, or if a storm is forecast.

A range of potential control devices were assessed for their suitability of application, taking into consideration the functional requirements of TASS, the physical aspects and space constraints, and each device's integration capabilities and limitations. On the basis of this review, the Easergy T300 device was chosen for use as the TASS platform for trial implementation. The compactness and configurability of this device provides the capability for testing the concept and prototype design at the trial sites. However, subject to successful demonstration of the technology, it may be possible to implement TASS by applying the algorithm via a range of alternative control devices. Further detail on the selection of the TASS control device and the options considered is given in Schneider Electric's 'LEAN Project Report'[13], provided in Appendix E.

The Easergy T300 platform comprises hardware and firmware and provides a modular application building system for the monitoring and control of electricity distribution networks. The modules used to provide the TASS platform are:

- 1 x HU250 - a Head Unit comprising the CPU (Central Processing Unit) with a communications gateway to provide comms to Control Room and other IT applications
- 2 x Easergy SC150 - a Switch Controller used for the monitoring and control of the switchgear

The connection between the T300 and the existing RTUs is via Ethernet cable, with power to the PLC provided from the same 24v power supply used for the RTUs.

The general purpose Input/Output ports (I/Os) available from the chosen Head Unit were just sufficient to provide the local indications and control specified for incorporation into the wall box, subject to the use of latching relays to represent both values for binary indications (rather than two separate indications).

Each of the chosen switch controllers provides sufficient I/Os to monitor and issue commands to a synchronising relay via a hardwired connection or via DNP3 over Ethernet. However, as it was demonstrated that the synchronising relays could communicate with the TASS PLC using the DNP3 protocol, the switch controllers could be replaced with an Ethernet switch to provide the required number of Ethernet ports.

[13] 'LEAN Project Report', Schneider Electric, September 2018

The TASS platform is housed in a wall box for installation at the substation. The 'TASS System and Algorithm Technical Specification' included a technical specification for the wall box and this was issued to the consultants to ensure the design conforms with standard SSEN requirements, and a copy of this specification is provided in Appendix F.

The wall box for the TASS trials has been designed to accommodate a range of the potential scenarios for deployment at two transformer substations, with one switch controller used per transformer and synchronising relay as described above. The current wall box supports a maximum of two transformers, however this constraint is based on the envelope of the casing chosen for the wall box. The modularity of the TASS wall box architecture could easily be expanded to accommodate three or more transformers through the use of additional T300 modules and a larger wall box, still using the same connection types (Ethernet and power). The potential requirement of extra Ethernet ports could be accommodated by including an Ethernet switch.

Figure 9 represents the modular elements of the TASS wall box architecture.

Figure 9 - TASS wall box architecture - source Schneider Electric

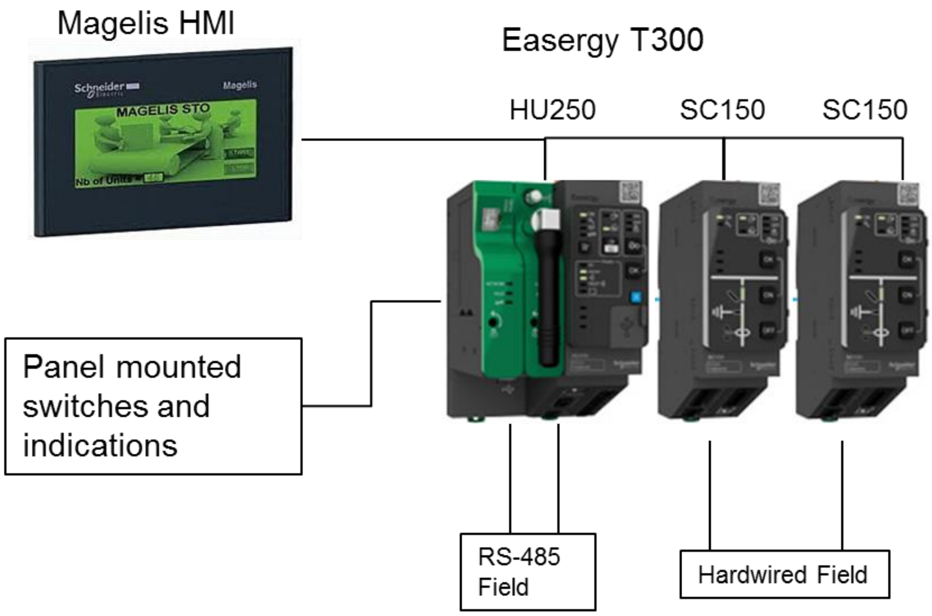
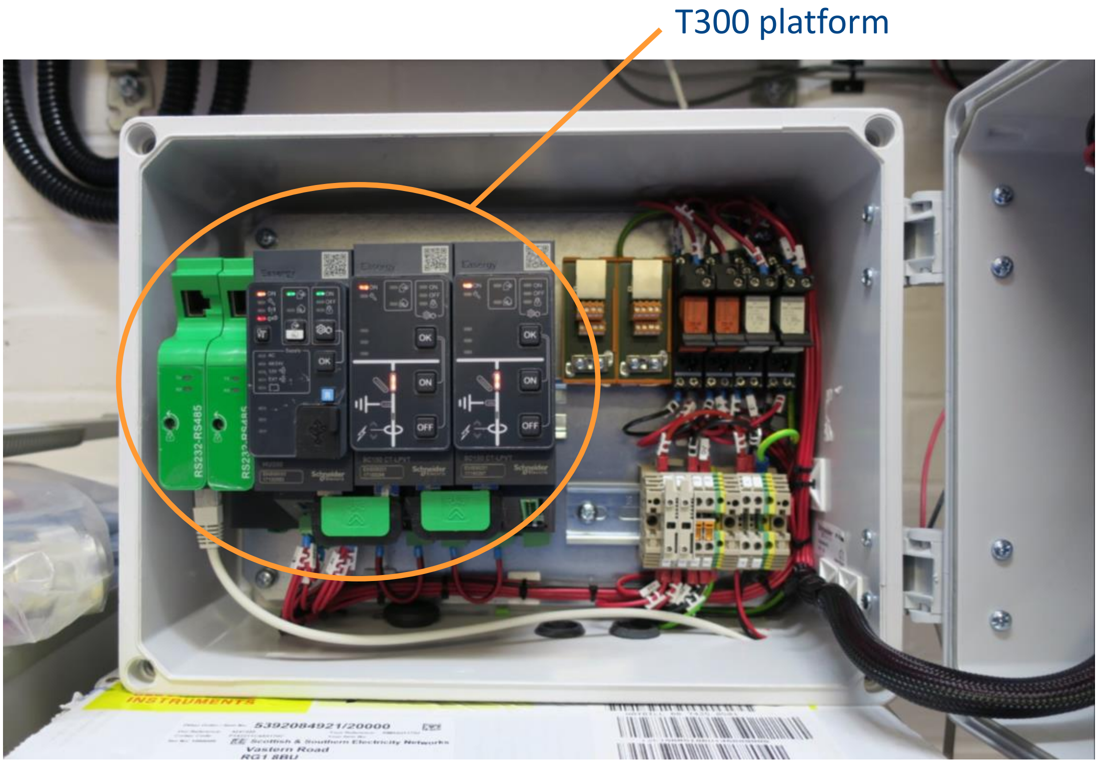


Figure 10 shows the TASS platform housed in a wall box during testing at SSEN's Protection laboratory, alongside terminal blocks for wiring to the casing LEDs & display, fuses, and the Ethernet & power supply cables. The external dimensions of the casing are 360mm x 270mm x 233mm (width, height, depth). Detailed design drawings are provided as Appendix G.

Figure 10 - TASS platform and auxiliary components housed within a wall box during bench testing



The synchronising relay selected to provide Point on Wave switching capability is Vizimax's MVX SynchroTeq unit. This will be used during the trial operational period to assess how effective these devices are in avoiding large inrush currents and voltage transients when energising the transformers. The disturbance recording functionality of the existing protection relays will also provide information on the magnitude and frequency of inrush currents and voltage variations for use when assessing any impact on power quality due to switching without use of the synchronising relay. Again, should Point on Wave switching be beneficial for roll out of TASS, alternative devices may also be suitable for providing this functionality.

Schneider Electric's 'LEAN Project Report' provides further detail on the considerations and decisions made in developing the TASS architecture.

TASS System Functionality

As described in Section 3 'TASS Development & Trial Implementation', the project team engaged with key staff from across the business to capture relevant requirements and create the functional specification for the TASS algorithm. These requirements relate to both operational and safety considerations, as we want to avoid any additional risk of transformer switching or energisation while there's someone within the switch room or near the transformers, and to minimise any risk of customer interruptions or other supply issues.

There are three key elements to the functional requirements for TASS, as follows:

- Operational Principles - these are central to the design of the system and its delivery to the business
- Operational Modes - these define the system states required to accommodate different operational situations
- Responses to SCADA data - this is necessary both for switching in response to substation loading and for identifying any potential issue with the network or other substation assets and responding accordingly

Eleven key Operational Principles were established to govern the design of the system and define how individuals with a range of roles would interact with it. These principles are summarised below, with further details provided in Appendix H.

➡ **1. Entering a trial substation**

Anyone wishing to enter a trial site primary substation is required to phone the NMC prior to entry, and an NMC Control Engineer must then Disable TASS and confirm to the person wishing to enter the substation that this has been done.

✓ The reason for adopting this principle is safety as it minimises the risk of TASS automated switching or transformer energisation whilst there is someone in the switch room or near the transformers.

➡ **2. The functionality to remotely supervise TASS is integrated into the DMS**

To provide visibility of the TASS system to Control Engineers, TASS status information and alarms together with TASS specific control commands have been incorporated into the DMS, PowerOn Fusion.

✓ This principle reflects the fact that the Control Room maintains the right to make and responsibility to enact decisions to Enable TASS and allow the TASS algorithm to commence operational control. This is important both for safety and for operational purposes.

➡ **3. Manual (remote) Disabling of TASS will cause the TASS transformer to be switched back in**

When TASS is Disabled manually by the Control Room, the TASS algorithm will switch the TASS transformer back in (if it is switched out) and then cease any further operation until an Enable TASS command is received.

✓ This principle allows the NMC to suspend TASS remotely via the DMS and return the substation to conventional operation, for example when someone wants to enter the substation, or at times of increased operational pressure such as when a storm is expected.

➡ **4. Manual (remote) or Automatic Locking of TASS will Not cause the TASS transformer to be switched in**

The system can also be remotely Locked by the Control Room without restoring the TASS transformer if it is switched out. This will cause TASS to halt any further operation until an Unlock TASS command is received.

✓ This principle allows the NMC to remotely suspend TASS via the DMS without triggering switching in situations such as:

- reports of a trespasser in the substation
- reports of a copper theft, or theft of the neutral earth wire

5. Local Pause functionality

It is possible to Pause TASS manually via the wall box in the substation, and this local non-auto setting provides a back-up plan in the event that SCADA control is lost and it is not possible for the Control Room to remotely Disable TASS but work needs to be undertaken within the substation, or a supply restoration response requires an abnormal network arrangement without any TASS activity.

✓ This principle ensures that it is possible to deactivate TASS onsite without causing switching and transformer energisation to occur whilst there is someone within the switch room or near the transformers.

6. Pausing TASS locally prevents the NMC from having any remote command capability over TASS and prevents the control algorithm from responding to any SCADA alarms or status indications

This reflects the fact that if TASS has been Paused locally (manually) then it is possible that there is someone on site, in which case the system must minimise the risk of switching and transformer energisation.

✓ This principle is adopted for safety to minimise the risk of the TASS transformer energising and switching back in whilst there is someone in the switch room or near the transformers who has needed to Pause TASS locally.

7. TASS Defective states

The TASS control system is designed to identify any situation where it may not be possible or safe for the algorithm to initiate switching, and to identify a fault with the control device or operation of the algorithm. Each of these situations will trigger a specific alarm in the DMS to notify an NMC Control Engineer who can then assess the situation and respond accordingly, drawing on field teams as required. The three TASS alarms incorporated into the DMS are:

- TASS Failed to Operate
- TASS Faulty
- TASS Crossover Point Error

A ‘Failed to Operate’ alarm indicates that a TASS switching operation has failed or that there may be a safety or operational risk associated with attempting to switch a transformer out or back in. In this situation the TASS algorithm will relinquish operational control (without restoring the TASS transformer if it is switched out).

The circumstances that will cause TASS to enter a ‘Failed to Operate’ state are as follows:

- TASS operation is not successfully completed when switching in or switching out the TASS transformer
- a SCADA alarm indicates an issue with the TASS transformer whilst it is switched out, as such there may be an operational risk associated with attempting to switch the transformer back in
- other network alarms/statuses indicate that it may not be possible or safe to switch a transformer out or initiate energisation and switching to reinstate the TASS transformer

✓ This response identifies situations where a technical or safety issue prevents TASS from controlling automated switching.

A 'Faulty' alarm indicates an internal problem with the TASS PLC or an issue with its connectivity to substation or network asset data. As such the TASS PLC will lose control capability (without restoring the TASS transformer if it is switched out).

✓ This reflects the fact that the TASS PLC must only control switching when it is functioning correctly and has access to all the input data required to make robust switching decisions.

A 'Crossover Point Error' indicates that TASS has not switched in the TASS transformer even though the load at the substation has increased above the TASS crossover point where both transformers should be in operation. The logic for this alarm is implemented within the DMS to provide an external check on TASS operation, and therefore in this case the algorithm will not have relinquished operational control, however the Control Room can intervene and both halt TASS operation and act to restore the TASS transformer immediately as necessary.

✓ This identifies a situation where the TASS algorithm has not initiated transformer energisation as designed to do.

In each case once the issue has been investigated and resolved, the Control Room can remotely re-Enable TASS which will clear the associated DMS alarm.

➡ **8. A sustained loss of communications will automatically Disable TASS**

The TASS algorithm will monitor data transfer between the DMS and the substation, and in the event that comms have been lost for 30 minutes[14] the algorithm will automatically Disable TASS, restore the TASS transformer if it is switched out, and then have no further operational control. The algorithm will automatically Enable TASS and resume switching control once comms have been re-established for a period of 30 minutes[14].

✓ This returns the substation to conventional operation in the event of a sustained loss of comms with the NMC, and the 30 minute period avoids frequent switching if comms drop out for a fleeting moment.

➡ **9. TASS Crossover Point implementation**

When TASS is Enabled, the control algorithm will monitor the substation loading and when this drops below the TASS crossover point, it will automatically switch out and de-energise one of the transformers. Similarly the algorithm will switch the transformer in when the load increases. The crossover point is implemented with high and low bands of 10%[14] around the defined crossover point, and the algorithm will only initiate switching if the load has been above the higher band or below the lower band for 60 minutes[14].

✓ This fulfils the objective of TASS, but avoids rapid switching in and out when the load fluctuates around the crossover level.

[14] figure applied via an algorithm setting such that the value can be altered as appropriate to meet operational requirements

10. TASS switching will alternate between transformers within the substation

The TASS PLC will alternate between the transformers within the substation[15] each time a transformer is to be switched out, such that transformer change-over takes place with each TASS switching event.

✓ This principle shares the switching duty between the transformers, and provides project data for a greater number of transformers.

11. Time-based transformer change-over events

The capability for time-based switching (as well as load-based switching) allows regular transformer change-over events to be scheduled to alternate the TASS scheme between the transformers within the substation, in the event that this has not occurred due to load-based switching over the course of a two week[14] period.

✓ This principle ensures regular switching of the transformers to provide assurance that the re-energisation procedure and transformers operate as expected in the situation where load-based switching only would otherwise keep one transformer off for long periods of low demand.

To apply these Operational Principles, TASS has five primary Operational Modes, defined as follows:

- **Enabled** - TASS has manually been set as operational remotely by the NMC - the algorithm takes operational control for switching the TASS transformer in/out
- **Disabled** - TASS has manually been set as not operational remotely by the NMC; or certain network alarms/status indications have caused the TASS algorithm to automatically suspend operation - in this case unless there's a fault or other network issue, the algorithm will restore the TASS transformer if it is switched out and then have no further operational control - equates to a return to conventional substation operation
- **Locked** - the system has been remotely halted by the NMC through a command that will not initiate transformer energisation if the TASS transformer is switched out; or manual remote or local switching (i.e. not initiated by TASS) or use of the Control Isolation Switch in the substation without TASS having been Disabled or Paused has automatically Locked TASS - in this case if the TASS transformer is switched out, it will stay out
- **Defective** - a situation has occurred where it may not be possible or safe to initiate switching, or there is a fault with the control device or operation of the algorithm, and so a TASS alarm must be raised - under certain defective situations the algorithm may lose further operational control, in which case if the TASS transformer is switched out, it will stay switched out - see Operational Principle 7 above for more detail
- **Paused** - TASS has manually been paused locally (on site) - no subsequent operation will occur, therefore if the TASS transformer is switched out, it will remain so

[15] note that for primary substations with more than two transformers, the decision as to whether to alternate the TASS scheme between all or just two transformers for BAU roll-out will be based on cost together with considerations relating to assessment of transformer health or implications for maintenance, however for the project trials alternating between two transformers is sufficient for the purpose of providing assurance that the transformers & TASS switching functionality is working as expected

Then in addition to monitoring substation loading, to identify any potential issue with the network or other substation assets and respond accordingly, the TASS PLC takes SCADA data from the existing substation assets for use as follows:

- transformer 33 kV and 11 kV switchgear status and bus coupler status data is monitored by the TASS algorithm to ascertain whether all the 11 kV bus sections are energised
- relevant operational alarms and status indication data from the 33 kV and 11 kV protection relays for each transformer within the substation is used by the TASS algorithm to identify any potential issue with a transformer or other assets
- 11 kV feeder FPI (Fault Passage Indicator) data from the feeder protection relays is used in the event that the bus section opens but no remaining transformer trips, to establish whether or not a network fault was detected on the TASS transformer section
- alarms from the LV power supply and battery are used to identify a fault with the substation auxiliary supply

The TASS algorithm is designed to respond to these SCADA alarms and status indications in a manner that mitigates the risk of customer interruptions in the event that an alarm may be associated with the non-TASS transformer being about to fail whilst the TASS transformer is switched out. The principles applied are to return the substation to conventional operation where possible (i.e. with both transformers switched in and TASS Disabled), but to also avoid any operational risk associated with attempting to switch the TASS transformer back in onto a fault.

The TASS algorithm's use of SCADA data is introduced in the 'TASS Algorithm' subsection below, and the system's responses to different scenarios identified through the data are detailed in Appendix I.

TASS Algorithm

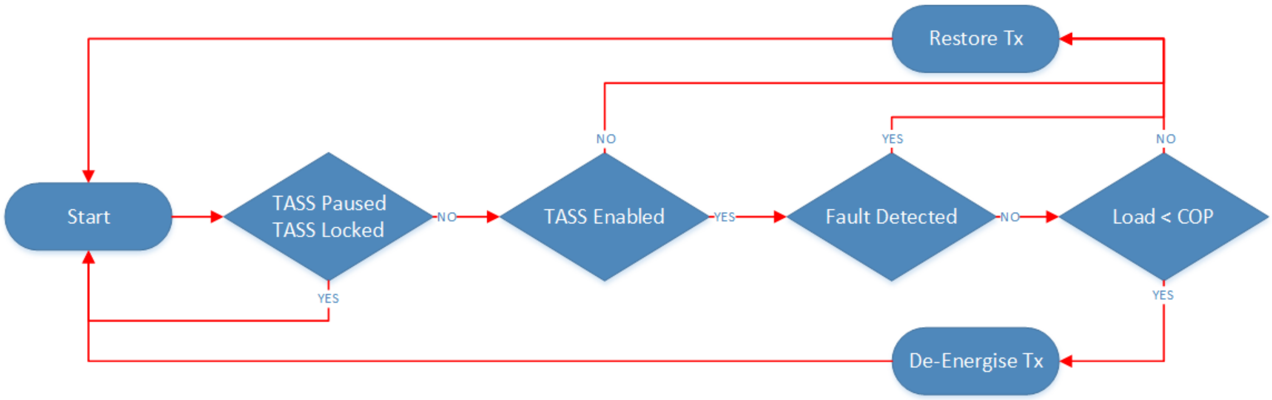
The LEAN project brings forward a concept trialled in the 1980's to reduce losses by switching out one transformer in a primary substation, however at the time manual switching was required, with no automation available to respond to changes in demand or network issues.

The TASS system now under trial on SSEN's network takes advantage of new monitoring and control technologies and advances in substation protection, communication and automation to provide a platform that automatically controls this transformer switching in a safe, efficient and reliable manner.

As described in Section 3, the specification for the TASS system was created drawing on the initial project work undertaken in Phase One together with additional detailed analysis and requirements capture during Phase Two.

The project team designed and developed the TASS algorithm in the form of a flow chart which details the data to be used by the TASS control device and the procedures which govern the system's response to different states or situations indicated by that data. A conceptual flow chart illustrating the very high level operation of the TASS algorithm is given in Figure 11.

Figure 11 - TASS algorithm conceptual flow chart



The detailed TASS algorithm flow chart represents all the required SCADA data points, tracks their connection from the RTU into the TASS logic, specifies the required TASS settings and timers, and defines the conditions which underlie the TASS decision making process. Additional information was recorded the accompanying 'TASS System and Algorithm Technical Specification'. The detailed flow chart and technical specification document are provided as Appendix J and Appendix K respectively.

To deliver the specified functionality and meet the requirements set out in the 'TASS System Functionality' subsection above, the algorithm needs to interact with substation systems such as protection, RTS, NMC and auxiliary supply. Based on the signals obtained from these systems, the algorithm then takes action to switch out or restore a transformer in response to both substation loading and specific alarms or status indications from other assets within the substation. Additionally, the algorithm needs to provide evidence to demonstrate its effectiveness and reliability, and to allow any issues experienced during operation to be assessed.

To provide a clear implementation of the logic, the TASS algorithm has therefore been designed with five segments, each of which has a distinct function within the algorithm. These segments are listed here, with descriptions provided in the text below:

1. DNP3 data point mapping
2. Initial data processing
3. Decision making
4. Switching sequence
5. Logging and monitoring

DNP3 data point mapping

In the DNP3 data point mapping segment all digital inputs, analogue measurements and control commands required to enable communication between the TASS PLC and RTU are declared. This element of the algorithm ensures that SCADA data received from the RTU are correctly interpreted, and that commands from the TASS PLC are sent to the correct device.

The specific DNP3 data points for any individual primary substation are documented in the SSEN 'Whitebook' for the substation. This is an Excel file which contains the SCADA comms signal list and information related to data types for each of the physical substation devices, in accordance with standard RTS specifications and processes. It was known that variations in RTU configuration settings, semantics, etc., would exist between different substations, requiring the DNP3 data points to be mapped for each substation, however the key elements of data available are common across the majority of primary substations.

As inputs to the TASS algorithm, then, the PLC takes SCADA data from the 33 kV and 11 kV switchgear, 11 kV bus coupler switchgear, 33 kV and 11 kV transformer protection systems, feeder protection relays and LV power supply system. An example of the 11 kV and 33 kV protection relay DNP3 data points used as inputs to the TASS algorithm is presented in Table 5, and the full set of SCADA input data is presented in Appendix I.

Table 5 - TASS Algorithm Inputs - Protection & Control Status Indications & Alarms

33 kV Protection Relay	11 kV Protection Relay
Switchgear Status ●	
● CB Closed	● CB Closed
● CB Open	● CB Open
● Earth Position Selected	● Earth Position Selected
● Isolator In Service	● Isolator In Service
Relay Health Indication Alarms ◆	
◆ Relay Disabled	◆ Relay Disabled
◆ Relay Failed	◆ Relay Failed
◆ Relay Offline	◆ Relay Offline
◆ Relay Overflow	◆ Relay Overflow
◆ Relay Restart	◆ Relay Restart
Operational Alarms ◆ & Status Indications ●	
◆ Main Bucholtz Alarm	◆ Auto Reclose Operated
◆ Aux Bucholtz Alarm	◆ DOC Trip
◆ Main Bucholtz Trip	◆ Protection Disabled
◆ Aux Bucholtz Trip	◆ Relay Function Bloc
◆ T/C Bucholtz Trip	◆ Relay Partially Failed
◆ Low Gas Stage 1	◆ Restricted Earth Fault Trip
◆ Low Gas Stage 2	◆ T/C Fail
◆ Motor Protection Operate P143	◆ T/C Supply Fail
◆ Protection Disabled	◆ Trip Circuit Fail
◆ Protection Function Block	◆ Trip Recloser Operated
◆ P2122 Bu Pr Op	◆ VT Fail
◆ Relay Partially Fail	◆ Winding Temperature Trip
◆ Spring Discharged	● Auto Reclose Lock
◆ Trip Circuit Fail	● Telecontrol Disabled
◆ Trip Recloser Operation	
◆ Winding Temperature Alarm	
● Telecontol Disabled	

Initial data processing

Data received and interpreted through the DNP3 mapping are then passed for initial data processing to determine the current substation loading, network configuration, status of circuit breakers and protection relays, and identify any alarms and warnings from the substation systems. Here, the algorithm assesses whether all the conditions are met to allow TASS to operate.

Decision making

When the TASS system is Enabled, it continuously monitors conditions at the substation and makes switching decisions as appropriate. The algorithm is designed to respond to substation load conditions and switch accordingly to reduce losses, and to alarms and status indications from other assets to maintain security of supply. This segment of the algorithm also has the following functions:

- enact the Enable/Disable, Lock/Unlock and Pause/Activate commands
- check for any non-TASS switching activity indicating possible human presence at the substation
- identify any comms issues between the RTU and central Control Room
- check whether the synchronising relays are available for use during 33 kV circuit breaker operation

Full detail on the TASS system's responses to different operational scenarios identified through the SCADA data is given in Appendix I.

Switching sequence

When the algorithm identifies that a transformer should be switched out or restored the switching sequence is initiated. Appropriate commands are sent to operate the 11 kV and 33 kV circuit breakers, with specified intervals between signals to ensure that the system is operating correctly after each switching stage. It is important to note that switching sequence cannot be interrupted once it is initiated. The TASS algorithm has two types of switching sequence for restoration of the transformer: normal and quick. Quick restoration (typically less than 5 seconds) is used when a loss of supply for some or all customers has been detected, with the purpose of restoring the supply as swiftly as possible whilst maintaining safety. The normal restoration sequence (typically less than 1 minute) is used under all other scenarios and incorporates additional checks to maintain quality of supply.

Logging and monitoring

To allow evaluation of the operation and effectiveness of the TASS system, and to assist in the investigation and resolution of any issues experienced during the trials, three log files have been implemented. The first log records data points such as statuses, alarms, flags, timers and commands issued, as relevant to the project team's analysis of the performance of TASS. In the second log, all faults are recorded together with their specific description and cause. Finally, the third log is used to record 10 minute average, minimum and maximum values for load measurements to allow calculation of the energy saved due to TASS operation.

The 'TASS System and Algorithm Technical Specification' and detailed flow chart were issued to the consultant engaged for Work Package 7, Schneider Electric, for evaluation and further discussion.

Schneider Electric subsequently developed the process to implement the TASS algorithm using the Easergy T300 platform. Programming was undertaken using the ISaGRAF API (Application Programming Interface), which aligns to the IEC 61131-3 standard for industrial automation and control programming. In addition, to simplify the process of DNP3 data point mapping and minimise the risk of errors, Schneider Electric developed an Excel tool to automatically generate the TASS DNP3 mapping from the specific Whitebook for a given substation. Further details on the process for development and implementation of the TASS algorithm and the mapping process is provided in Schneider Electric's 'LEAN Project Report'.

The implementation of the TASS algorithm was an iterative process with Schneider Electric working closely with the project team at both Schneider Electric's factory testing laboratory and on the TASS test system set up in SSEN's Protection laboratory. The change request process was managed through Change Request Notes (CRN) to record all amendments required to the T300 coding in addition to modifications to the TASS algorithm specification, RTU configuration, protection relay settings, etc. These changes were captured and tracked in the CRN log, illustrated in Figure 12.

Figure 12 - Extract from the CRN log for TASS algorithm development

Change ID	Change description	Change Raised By	Change Raise Approved By	Raised at Algorithm Version	Implemented in Algorithm Version	Flow chart Updated	Schneider informed By	Schneider informed Date	Implemented on T300	Tested on T300 Date	Lab Tested Date	Change Implementation Approved by	Change Approved Date	T300 Software Version Release	Release Date	Status
1	include dV calculations ABS value of T1_V - T2_V	Juanlu	Maciej	V0.7	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed
2	Include multiple bus coupler detection	Juanlu	Maciej	V0.7	V0.9	Closed	Maciej	11/12/2017	Suspended	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Open
3	reset timers when TASS is enable/disable but T3 by active All timers decreased by 15 min when Activate - implemented as condition active for more then 15 min	Juanlu	Maciej	V0.7	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed
4	time synchronisation	Juanlu	Maciej	V0.7	V0.9	Closed	Maciej	11/12/2017	In_Progress	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Open
5	FeederCB monitoring for FPI	Maciej	Maciej	V0.8	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed
6	Change TASS Active time delay from 5 to 15 minutes - use out-of-band time reset ? (T1, T2 reset, T3 and T7 add 15 min longer)	Maciej	Maciej	V0.8	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed
7	TASS alarm disables the TASS	Maciej	Maciej	V0.8	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed
8	telecontrol Disable - TASS disable and/or failed to operate	Maciej	Maciej	v0.8	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed
9	spring discharged - treat as alarm	Maciej	Maciej	V0.8	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed
10	Change Change over flow chart to go back to start and use a new timer for 15 min delay	Maciej	Maciej	V0.8	V0.9	Closed	Maciej	11/12/2017	Closed	N/A	N/A	09/01/2018	09/01/2018	N/A	N/A	Closed

TASS Algorithm Testing

To ensure that the system's decisions making and control capabilities operate satisfactorily (including compliance with the requirements of the algorithm specification, use of the correct data, and issuing of appropriate control and status signals), the PLC programmed with the TASS control algorithm has undergone a number of testing stages prior to commencing trial operation. These are introduced here, with detailed descriptions given below:

- Factory Acceptance Testing (FAT) at Schneider Electric's Chippenham laboratory prior to delivery of the device
- bench testing of the algorithm and the device's integration with SSEN protection equipment and comms systems at SSEN's Protection laboratory
- installation of the PLC at the trial sites for initial site testing & observation of the algorithm's control decision (no automated switching control)
- full on site testing activities during the TASS commissioning process at the trial sites

Factory Acceptance Testing

The first stage of testing undertaken by Schneider Electric comprised 'Hardware in the Loop' (HIL) testing.

HIL simulation uses numerical representations of all related dynamic systems to emulate the complexity of the environment in which the system under test will operate. This allows the interaction of the system and response of the control algorithm to different simulation signals to be tested. The operation of the system can then be refined as necessary to de-risk the move to testing in a real environment with connection to external assets or systems.

Further information on this stage of testing is given in Schneider Electric's 'LEAN Project Report'.

Bench Testing

Bench testing allows the system's interaction and comms with the electrical and ICT devices that would be found in a substation to be evaluated.

For TASS testing, a test system replicating a real substation environment was set up in SSEN's Protection laboratory. The system's responses to different operational scenarios replicated in this environment were observed, and in addition to testing the algorithm, this provided a sense check on the design of the scheme and allowed additional potential scenarios and considerations to be identified and addressed at the development stage.

The laboratory test system consisted of:

- 1 x Schneider C10e RTU, as currently used widely across SSEN's network
- 2 x MiCOM 142 relays to simulate transformer 11 kV protection relay indication and alarms with axillary relays for 11 kV circuit breaker operation and status
- 2 x MiCOM 143 relays to simulate transformer 33 kV protection relay indication and alarms with axillary relays for 33 kV circuit breaker operation and status
- 1 x MiCOM 142 relay to simulate 11 kV feeder protection relay indication and alarms with axillary relays for 11 kV circuit breaker operation and status
- a TASS wall box housing the T300 PLC
- 2 x SynchroTeq Point on Wave switching relays with communications gateways
- an Omicron CMC356 secondary injection test set to simulate substation load and voltages
- an Ethernet switch for tracing communication traffic as an external means of observing the signals sent
- a comms link to the NMC and PowerOn Fusion test environment via DNP3 and WISP protocols

Further, prior to purchase of the synchronising relays selected for incorporation into the TASS scheme, one device was provided by the product vendor, UK distributor Enspec Power, on a trial basis to allow bench testing of the device's communication capability at the Protection laboratory.

All components of the test system were set up as close to those found at the TASS trial sites as possible. For example, the configuration of the RTU could be adapted to reflect the configuration at either trial site, similarly the protection relay settings from either of the sites could be uploaded to the test environment relays. These aspects provided confidence in the testing process, and assurance regarding the operation of the TASS system when installed on site.

To guide the testing process and maintain consistency following modification of any aspects of the TASS algorithm or other component of the system, the 'TASS Algorithm Testing Specification' was created. This document was used to record testing results and note all identified issues. A copy of this testing specification document is provided as Appendix K. Each of the required changes and modifications to the algorithm were then recorded and managed through the CRN process described in the 'TASS Algorithm' subsection above.

Bench testing of the TASS algorithm and hardware platform was used at various stages of development to verify the following aspects of the system:

- correct data point mapping on the TASS PLC
- correct operation of the algorithm
- system stability when operating
- consistency of operation
- efficiency of operation
- speed of communication and flow of traffic between the substation IEDs, RTU & TASS PLC
- correct operation of the link with the NMC, including the controls, status indication and alarms within the DMS and the TASS response to a loss of comms with the NMC
- the effect of TASS operation on other substation systems
- the impacts of a TASS system failure and effect of this on other substation systems

This bench testing approach proved to be very effective, and issues with both the TASS algorithm and the system's integration with existing assets or specific substation configurations were identified and rectified prior to site installation. Had these issues been discovered during site testing, they may have been time consuming and costly to address due to the need to arrange additional outages and schedule resources to complete further testing or commissioning activities.

Site Testing & Commissioning

Once testing had been completed to demonstrate satisfactory operation of the system, the equipment was then installed for real world testing with electrical equipment as part of commissioning. The commissioning activities are described in Section 5 'TASS Installation & Commissioning'.

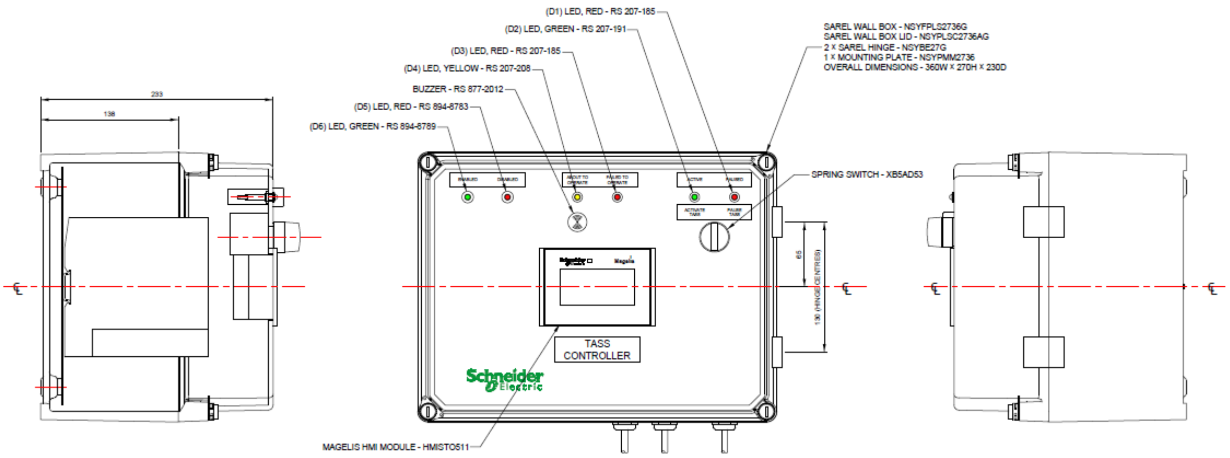
TASS Wall Box

The TASS PLC is housed in a wall box for installation at the substation. The 'TASS System and Algorithm Technical Specification' created and issued to the consultants included the specification for the wall box, and defined the communication ports, power supply, and cable terminations needed together with requirements for the TASS interface panel to allow local interaction with TASS. This is specification provided in Appendix F.

Following a review of these requirements and selection of the T300 platform for development and implementation of the TASS algorithm, the TASS interface panel was designed by Schneider Electric.

A design drawing including the main panel view is given in Figure 13, and the detailed design drawings showing the wall box, DIN rails and fixings, and TASS components can be found in Appendix G.

Figure 13 - TASS wall box design - source Schneider Electric



The TASS interface panel provides local indication and control functionality for the TASS PLC and auxiliary equipment as follows:

- 6 LEDs - to indicate the operational state of the TASS system: 2 LEDs to indicate whether TASS is Enabled or Disabled, 2 LEDs to show whether TASS is Paused or Active, a single LED to indicate that a TASS switching sequence is in progress (About to Operate), and a single LED to indicate a Failed to Operate alarm
- a touchscreen HMI (Human Machine Interface) - to provide additional information about the status, settings and timers of the system, and allow designated members of the project team to interact with the PLC and change these settings if necessary
- a buzzer - when a TASS operation is in progress an audible indication is also given which lasts throughout the TASS switching sequence, under normal restoration this commences 5 seconds prior to switching however for quick restoration it is not possible to provide a prior indication
- a selector switch - to provide the local 'non-auto' Pause functionality as a back-up option in the event that comms with the NMC are down and it is not possible for the Control Room to Disable TASS remotely

The TASS wall boxes were installed at the substation in close proximity to the existing RTU comms cabinet, and the PLC is connected to the RTUs via Ethernet cable for data communication, with a SWA (Steel Wire Armoured) cable used for the PLC power supply. Individual Ethernet cables are also used to provide the comms connection from the TASS PLC to each synchronising relay.

Integration of the Synchronising Relay

Vizimax's SynchroTeq MVX unit was selected as the synchronising relay to provide Point on Wave (PoW) switching capability within the TASS scheme. This relay offers very good functionality and meets the TASS requirements for transformer energisation using bank operated 33 kV circuit breakers. However, the MVX relay does not support the DNP3 protocol directly and so a SynchroTeq communications gateway is required for DNP3 communication. In addition, this is a relatively new device with no prior deployment on GB distribution networks, and SSEN have limited experience of the use of this type of device and mode of switching.

As these factors provide additional risks or challenges for TASS system integration, one relay with an associated comms gateway was provided on a trial basis by the product vendor, UK distributor Enspec Power, to allow bench testing of the device's DNP3 communication capability.

Following purchase, two SynchroTeq relays were then incorporated into the TASS test system at SSEN's Protection laboratory to verify the operation of the units within the TASS architecture. This testing demonstrated that control signals are correctly sent by the TASS PLC and received and enacted by both SynchroTeq relays, and that status and feedback data are correctly received by the TASS PLC.

For TASS use each SynchroTeq relay must be integrated with the following two systems to exchange status and feedback data, and issue close and open commands to the 33 kV circuit breaker:

- TASS platform
- 33 kV switchgear or protection relay

As bench testing had demonstrated that the SynchroTeq relay could communicate with the TASS PLC using DNP3, the connection to the TASS platform is via Ethernet cable, rather than via hardwired connection into a switch controller.

The use of a DNP3 link to the protection relay would allow close and open commands from the SynchroTeq relay to be executed in the same way that the TASS PLC operates the 11 kV and 33 kV circuit breakers when the SynchroTeq relays are not available. From a TASS system integration perspective this would be the simplest approach as it requires minimum modifications to the existing substation systems. However, the SynchroTeq relay requires a consistent time response from the circuit breakers, particularly when the close command is issued, to achieve the best results with regard to switching at the optimal point on wave. Consequently, the preferred option was for the SynchroTeq relays to control the circuit breakers' close and trip coils directly via a hardwired signal to avoid any time delays in signal transmission introduced by the protection relay and DNP3 link. This latter approach has therefore been implemented for the TASS trial system.

To operate effectively each SynchroTeq relay also requires the following:

- 33 kV circuit breaker status - to ascertain whether it's possible to open/close the circuit breaker
- 33 kV voltage - to provide a reference voltage for the relay (single phase)
- transformer 11 kV side voltage - required for residual flux assessment (three phase required)
- transformer currents - to monitor transformer inrush current (three phase required)
- 110 DC supply voltage

The relays were installed within the switchgear panels at the trial substations, and a spare auxiliary contact was used to provide the circuit breaker status and 3 phase transformer current measurements from the back-up protection relay. The back-up protection relay was used due to both proximity and the recognition that this would be less critical should there be any adverse effect due to incorporation of the synchronising relays. The 110 DC supply voltage was also available from the switchgear panel.

The voltage measurements are taken from external devices by the installation of new pilot cables. The 11 kV three phase voltages are taken from the Automatic Voltage Control (AVC) unit, and the 33 kV red phase voltage, used as the reference voltage, is sourced from the VT (voltage transformer - a voltage measurement device) located in the 33 kV bus section panel.

To record these changes, the protection system drawings for each substation were updated to include the synchronising relays.

The synchronising relays will provide information on the magnitude and frequency of inrush currents and voltage variations during switching, which can be used to assess how effective these devices are in avoiding large inrush currents and voltage transients when energising the transformers. The disturbance recording functionality of the existing protection relays will also be used to monitor power quality to provide a comparison when switching without use of the synchronising relay.

TASS Integration with SCADA

To integrate the TASS system with SCADA, the configuration of the existing RTUs was modified as follows:

- add the TASS PLC as a secondary DNP3 host
  The DNP3 host status enables the flow of information between the TASS PLC and the existing RTU, to access data from the existing substation devices connected to the RTU and to issue switching signals as appropriate. The substation SCADA data used as inputs to the TASS control algorithm are described in the 'TASS Algorithm' subsection above.
- add the TASS PLC as a new IED
  The IED classification enables the PLC to send TASS specific status indications and alarms to the DMS via SCADA, to provide visibility of the TASS system to Control Engineers, and to receive TASS control commands from the DMS, allowing Control Engineers to remotely suspend TASS operation when required. The information and commands available through the DMS are described in the 'TASS Integration with the DMS' subsection below.
- add host line statistics for monitoring the RTU - NMC comms link
  This adaptation was required as the RTUs do not currently monitor comms connectivity to the Control Room, and TASS must be able to identify a sustained loss of comms. The applied modification counts the number of messages (which may be command or polling messages) received by the RTU using host line statistics data, and times the period between messages. Ordinarily this count increases steadily, however when the count has not increased over a 30 minute period, TASS infers that comms have been lost and Disables the system to return the substation to conventional operation. Similarly, TASS re-Enables itself when the count has been increasing for 30 minutes.

To apply these required changes, a 'TASS template' for RTU configuration was created and uploaded to the RTUs at each trial site by the RTS team, in accordance with standard RTS processes. A record of these changes is also held within the RTS database for reference.

TASS Integration with the DMS

TASS Commands, Status Indications and Alarms

The TASS specific functionality incorporated into the DMS comprises digital input signals and both digital and analogue output signals, each of which are communicated between the PLC and DMS via SCADA. The commands, status indications and alarms available through the DMS are as follows, with descriptions of these given in the text below:

commands

- Enable TASS/Disable TASS
- Lock TASS/Unlock TASS

status indications

- TASS Enabled/Disabled
- TASS Locked
- TASS Paused
- TASS Operating T1
- TASS Operating T2
- Amps Away from TASS Crossover Point (analogue signal)

alarms

- TASS Failed to Operate T1
- TASS Failed to Operate T2
- TASS Faulty
- TASS CoP (Crossover Point) Error

The 'Enable/Disable' command gives Control Engineers the ability to control when TASS is in service (with automated switching control) or out of service (with the substation returned to conventional operation), and the 'Enabled/Disabled' status confirms that the command was executed correctly. The 'Lock/Unlock' command allows Control Engineers to halt operation of TASS (thereby preventing any further automated switching in or out) with this command confirmed by the 'Locked' status. The Paused status indicates that TASS operation has been suspended on site via the TASS wall box.

When a TASS switching sequence has been initiated to switch out or re-energise a transformer, the status 'TASS Operating Tx' will be sent to the Control Room indicating which transformer is being switched in or out.

The 'Away from TASS Crossover Point' analogue signal provides an indication to Control Engineers as to whether the system may be close to triggering a switching operation. This signal is expressed in Amps and indicates by how much the substation loading needs to change for TASS to initiate a switching sequence. If the value of this signal is zero, this means that the loading has passed the crossover point and the TASS algorithm has started timing to determine that the load is staying around that level (to avoid switching in response to brief fluctuations in load), and so TASS may be due to operate very soon. Conversely a high value suggests that TASS operation in response to substation loading is unlikely. However, it is important to note that switching sequence could still be triggered in response to abnormal or network fault conditions detected via SCADA data.

The alarms then inform the Control Engineers when there's been an issue with TASS operation, or whether the system has identified something which means that it may not be possible or safe for the algorithm to initiate switching. Here:

- 'TASS Failed to Operate' indicates that TASS has failed to successfully complete a switching sequence, or that network data means there may be an operational risk in trying to switch a transformer, and so the system has surrendered control
- 'TASS Faulty' means that there's an internal problem with the TASS device or an issue with its connectivity to substation data, and so again the algorithm will halt operation as it doesn't have all the input data it needs to make robust switching decisions
  and
- 'TASS CoP Error' means that for whatever reason, the control device hasn't switched in the transformer even though the load at the substation has increased above the crossover point where both transformers should be in operation - essentially this identifies an error where the TASS algorithm hasn't initiated transformer energisation as it's been designed to do

If any of these alarms is raised the Control Engineer can then respond to the issue taking into account other information available in the DMS, and act to restore a transformer manually if necessary and safe to do so.

In contrast to the first two alarms, the 'TASS CoP Error' alarm is implemented within the DMS to independently validate the operation of the TASS algorithm. This alarm will be raised if TASS is in operation but the status (i.e. whether or not a transformer is switched out) does not correspond correctly to the loading on the substation, as determined by the calculations built into the DMS.

DMS User Interface

To create the user interface to be incorporated into PowerOn Fusion, a TASS template was created and issued to the NMC Cartography team.

This template was applied to each substation where TASS was to be deployed, and examples of the resulting PowerOn Fusion representations are shown in Figure 14 and Figure 15. In the main Schematic view, information on whether TASS is in operation or not is clearly displayed. In addition to providing information to the Control Room, this also provides a clear prompt allowing Control Engineers to access the commands (via a menu in keeping with other PowerOn Fusion commands) and Disable TASS if substation access is requested. Each of the TASS statuses and alarms are then displayed in the PowerOn Fusion Alarms view.

Figure 14 - TASS information incorporated into the main PowerOn Fusion Schematic view for each trial site

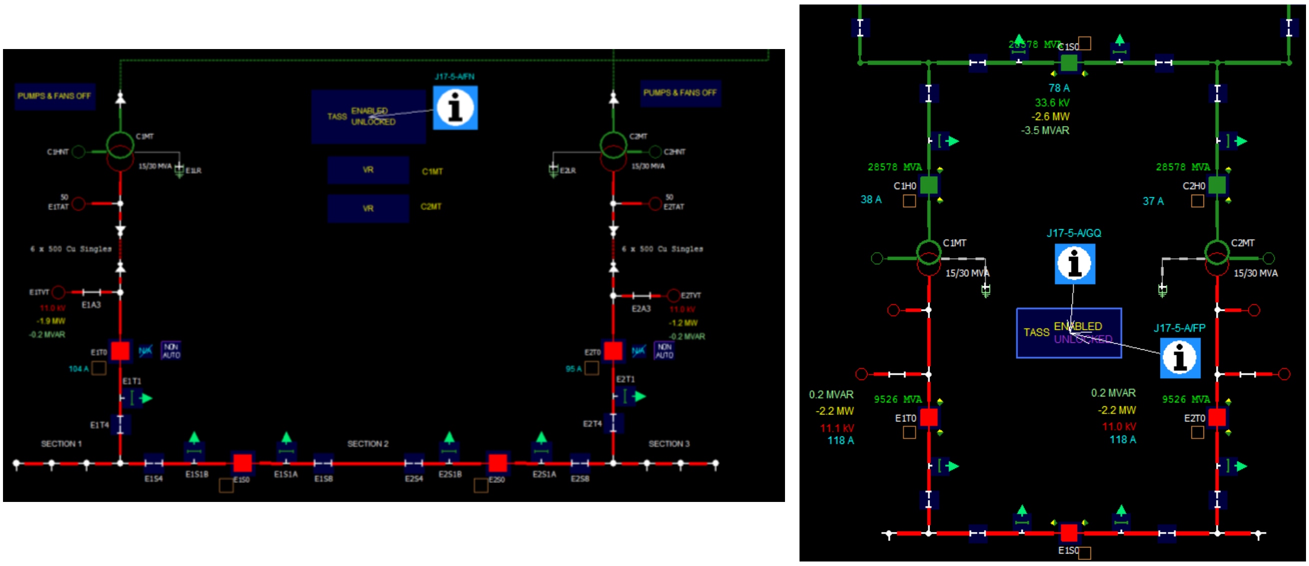
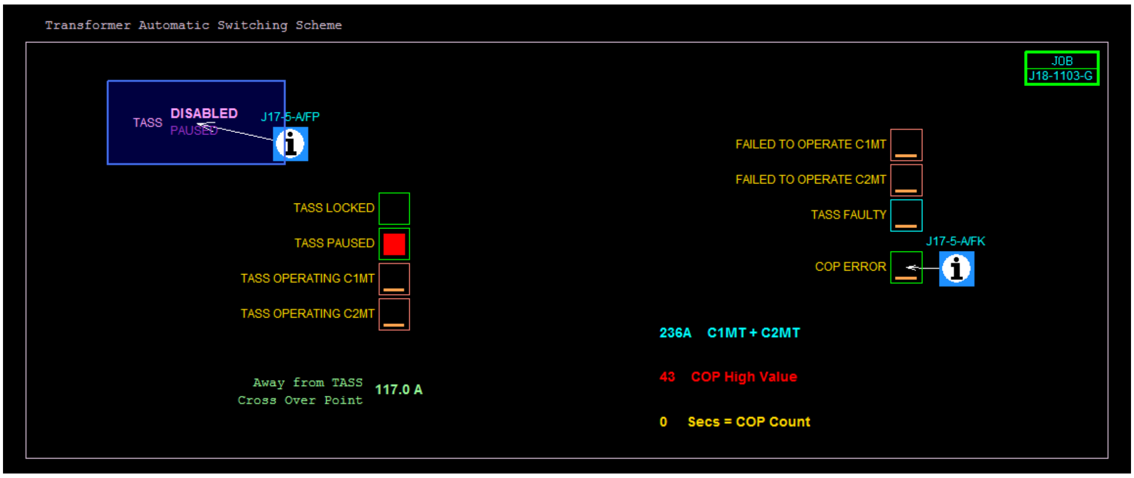


Figure 15 - TASS status information and alarms incorporated into a PowerOn Fusion Alarms view



DMS Data Repository

All the TASS related DMS data is recorded and stored in SSEN's data historian system, PI, requiring 8 PI Tags (7 digital and 1 analogue). This log provides a record of TASS operation which can be viewed through PI and monitored by the project team. The data available allows the performance of the system to be evaluated with regard to the number of TASS operations seen and the associated triggers for TASS switching, and information on the duration of TASS operation together with load information allows the losses savings to be calculated. This data is also important to support the investigation of any potential issues which may be experienced with the system.

The TASS PI Tags were added to the data repository by the NMC Cartography team, in line with standard business practices.

NMC Site Work Log

In addition to incorporating TASS into the DMS, operational flags relating to the two trial sites have been added to the NMC's 'Staff on Site' database by the Cartography team. These provide a prompt to Cartographers or other NMC staff who receive a call from anyone notifying the NMC of their intention to access a substation, including SSEN staff and third party contractors, to ensure that the EHV Control Desk are contacted so that TASS operation can be suspended before anyone enters the site, in line with the Operational Principles set out in the 'TASS System Functionality' subsection above.

5 TASS Installation & Commissioning

This section describes the installation and commissioning activities associated with the different aspects of the TASS trial system.

This details 'what' was done to deploy the technology, and is aimed at those considering the deployment of TASS or similar systems on their own network areas.

The work is presented under the following subsections:

- TASS Wall Box Installation
- TASS System Commissioning
- Synchronising Relay Installation & Commissioning
- Online DGA Monitoring System Installation

The time and resource requirements associated with the installation and commissioning activities described here are summarised in Section 3 'TASS Development & Trial Implementation'.

TASS Wall Box Installation

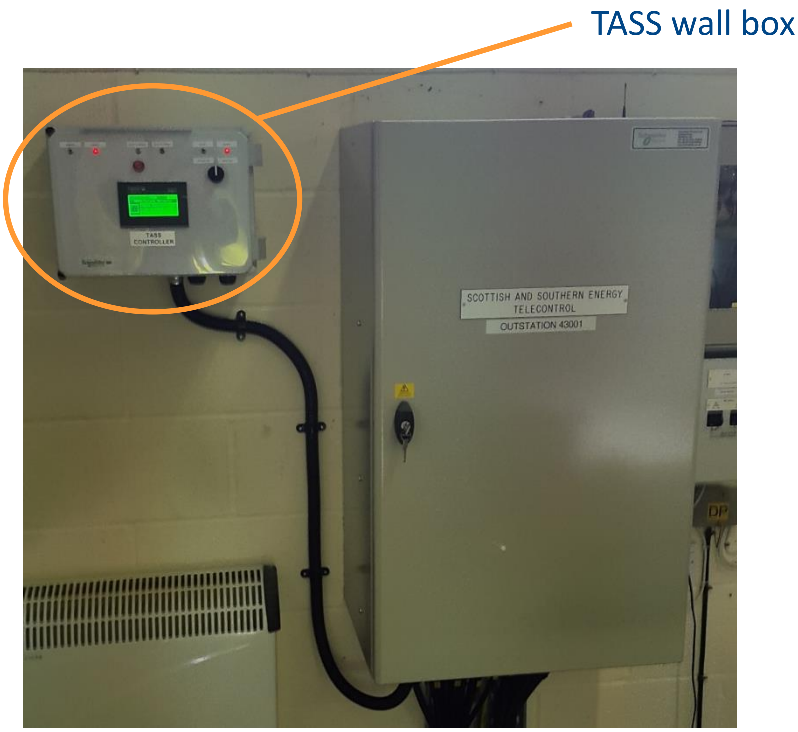
Prior to installation at site, the wall box housing the TASS platform was assembled and factory tested by Schneider Electric, then subsequently bench tested on the TASS test system at SSEN's Protection laboratory. Information on these testing activities is given in Section 4 'TASS System Design & Integration'.

The physical installation of the wall boxes took place in two stages: mounting of the wall box containing the TASS control device, followed by connection of the control device to the power supply and RTU.

For the first stage there was no requirement for any outage as this activity solely comprised the fitting of the wall box in a suitable location within the substation, and this task was carried out by two Schneider Electric Fitters. For the second stage, an RTU outage was required to allow a connection to be made to the 24v DC power supply, and an RTS engineer was engaged to update the configuration of the existing RTU with the TASS template described in Section 4, and connect the Ethernet cable from the TASS PLC to the RTU.

Figure 16 shows the wall box installed at Gillingham primary substation. The black ducting between the wall box and the existing cabinet contains the Ethernet cable which connects the TASS PLC to the RTUs and synchronising relays, together with the 24v power supply cable for the PLC.

Figure 16 - TASS wall box connected to the RTU within the telecontrol cabinet



Once the connections had been made and the RTU configuration updated, tests were run to confirm that no issues had been introduced for the standard operation of the RTU and its communication with the NMC. Additionally, basic tests were run to establish that the TASS PLC was communicating with the RTU. At this stage, only some of the data point mapping items were checked to verify that the communication link between the two devices was stable. Information on the detailed commissioning process is given in the 'TASS System Commissioning' subsection below.

In parallel, a 'TASS template' was implemented within our DMS, PowerOn Fusion, by NMC Cartographers prior the site commissioning of TASS. This template is applied individually to the sites where TASS is to be deployed, and allows TASS status information and alarms together with TASS control commands to be available to NMC Control Engineers via the DMS.

TASS System Commissioning

For operational commissioning of the system, a Commissioning Plan was drawn up by Schneider Electric as the consultants engaged for the site installation work. This plan was reviewed and signed off by the LEAN project team in consultation with SSEN Protection and RTS staff.

The plan was created with reference to the TASS system design, the existing site protection and RTS systems, other site specific conditions, and the associated risks. Its purpose was to specifically confirm communications between the

TASS PLC and existing RTUs, and correct operation of the TASS equipment and control algorithm. The activities set out in the Commissioning Plan therefore include:

- function testing to ensure that all signals from the protection relays are received by the TASS PLC
- simulation of different circuit breakers states to confirm that signals are received by the TASS PLC
- secondary injection testing with the protection relays to confirm simulated analogue readings are received by the TASS PLC, and to confirm operation of the disturbance recorder
- function testing of the local Pause/Active control functionality, including testing under various scenarios (for example under different TASS operational modes, and when the system was Disabled or Locked)
- simulation testing of all remote commands, including testing under various scenarios (for example under different TASS operational modes, and when the system was Paused locally or Locked)
- function testing of the control of the circuit breakers by the TASS PLC
- simulation of load changes by secondary injection testing (simulating the load on one transformer to imply an overall substation loading such that the algorithm switches the TASS transformer)
- function testing under normal operation
- function testing under fault conditions
- signal checks on comms back to the DMS to verify that all status indications and alarms are shown correctly and confirm that the NMC have the ability to Enable/Disable and Lock/Unlock TASS
- restoration of all telecontrol links to their previous, standard state, returning the substation to conventional operation
- a live test with TASS left operational overnight and the NMC Control Room and on call Field Staff made aware of this commissioning activity should there be a failure of TASS automated switching operation

Site specific plans were then drawn up and the Commissioning Plan for one of the trial site is provided as Appendix L. This gives full details of the specific steps taken on site during each day of commissioning.

The commissioning work was undertaken by Schneider Electric staff under the supervision of the LEAN project team, and with SSEN Protection and RTS staff present as required for acceptance testing. Accordingly, the Schneider Electric SAP agreed the proposed switching schedule and arranged access and transformer outage requirements with the Control Room Planning team, in line with standard SSEN processes. Each day of commissioning on site similarly followed standard SSEN procedures, with Point of Work Risk Assessments (POWRA) completed, any manual switching required carried out by the SAP, and issuing of the LOA (Limitations of Access) consent by the SAP prior to work commencing.

The injection and simulation testing allowed the commissioning team to replicate different situations and assess the response of the TASS system prior to enabling the comms link between the TASS PLC and the circuit breakers. In addition to demonstrating the operation of TASS, these tests also provided evidence of the correct mapping of all DNP3 data points required for SCADA integration - as described in Section 4 ‘TASS System Design & Integration’ this mapping translates the substation specific data items from different existing devices to the data points used as inputs to the TASS algorithm.

Further commissioning activities were then completed with the TASS PLC automatically issuing signals to control switching of the circuit breakers.

The results from this testing were recorded in a ‘TASS Site Testing Specification’ document for each site, and an example of this is provided as Appendix M.

Once TASS had been fully commissioned at both trial substations, TASS was activated at both sites on the same date to allow the start of the trials to be clearly communicated to operational staff.

Synchronising Relay Installation & Commissioning

The synchronising relays incorporated into the TASS scheme use Point on Wave switching to limit inrush currents during energisation of a transformer. The TASS system is able to operate with or without these relays, to allow the effects of switching to be assessed as part of the trial.

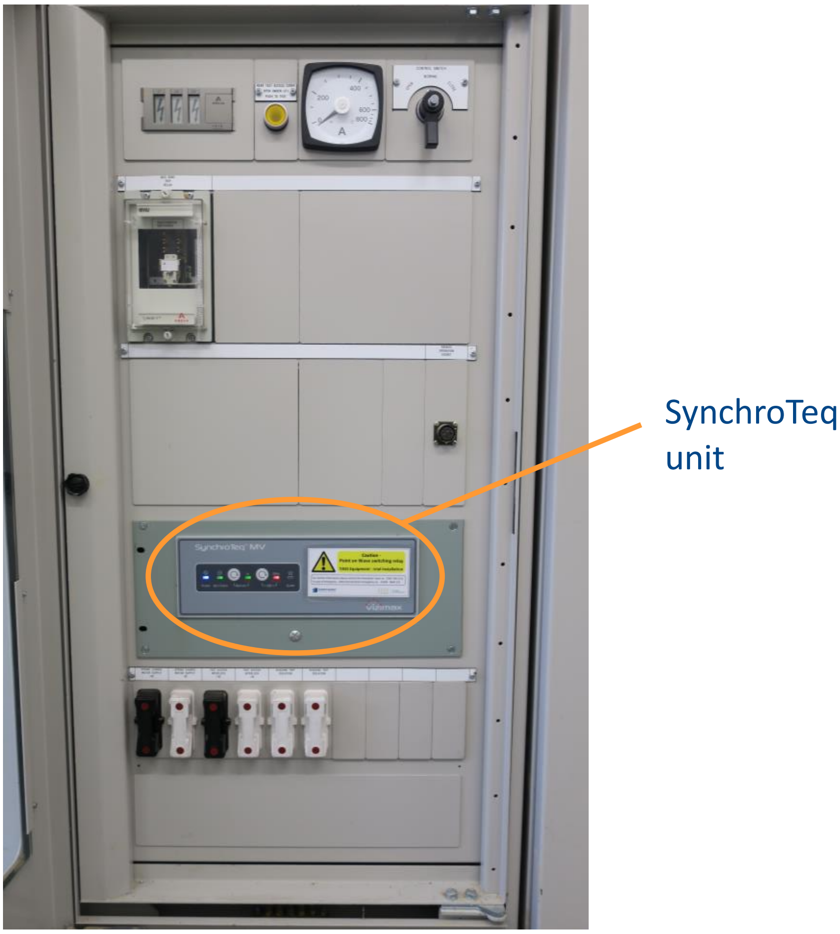
Prior to purchase and installation, the synchronising relays were bench tested to confirm their ability to communicate with the TASS PLC and ensure that the relays could be successfully integrated into the TASS scheme.

A procedure to install the relays within existing switchgear panels and incorporate them into the TASS scheme was then prepared. As with TASS installation and commissioning, transformer outages were required due to the planned switching activities, and again these were arranged following standard SSEN processes. Additionally, the plates to hold the synchronising relays and their communications gateways were pre-assembled by Fitters in Schneider Electric’s workshop in preparation for installation on site.

During installation, the plates were inserted into spare slots in the existing switchgear panels within the substations, and the wiring was connected to the signal terminal blocks during the transformer outage. Pilot cables were connected to provide the synchronising relay with 11 kV and 33 kV voltage measurements from the AVC panels and bus coupler respectively, to provide data for the relay’s switching calculations. Finally the Ethernet cable was connected to allow communication between each synchronising relay’s communications gateway and the TASS PLC.

Figure 17 shows a SynchroTeq MVX relay installed within an existing switchgear panel

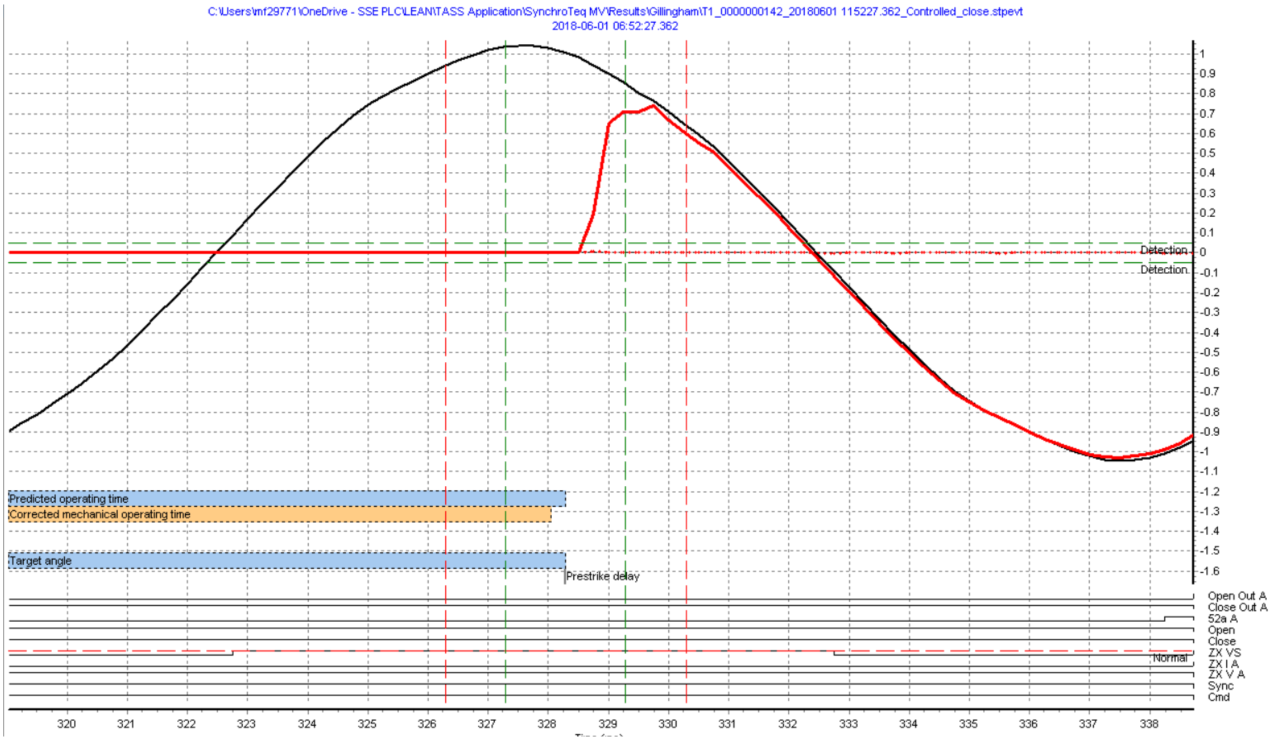
Figure 17 - SynchroTeq MVX relay installed within the switchgear panel



In order to commission the synchronising relays it was necessary to operate the 33 kV circuit breaker a number of times without use of the relay to measure and assess the consistency of the closing time for the circuit breaker and auxiliary contacts. These time measurements allow initial settings for the synchronising relay to be established. To monitor switching events both with and without use of the relay Vizimax's Event Analyzer software was used to display the waveforms and circuit breaker operation captured by the SynchroTeq relay.

The next stage of commissioning was to ensure that the circuit breakers close within a predicted window of time when controlled by the relay. This window is indicated by green vertical dashed lines in Figure 18, which shows an image taken from the Event Analyzer. It can be seen in this image that the predicted operating time (blue horizontal bar) and actual closing time (orange horizontal bar) are very close to each other, thereby confirming the correct operation of and settings for the synchronising relay.

Figure 18 - SynchroTeq relay commissioning image showing optimal circuit breaker operation timing



As described in Section 3 'TASS Development & Trial Implementation', at Hedge End substation the relays were installed during the site visits for installation of the TASS system as DNP3 comms between the PLC and the synchronising relay had been successful demonstrated at that point. At Gillingham the synchronising relay were installed after TASS system was fully commissioned.

Following installation of the synchronising relays, the protection system drawings for each substation were updated to include the relays.

Online DGA Monitoring System Installation

The online DGA system was installed and commissioned by Camlin Power as the providers of the TOTUS system, with activities overseen by the LEAN project team.

As noted in Section 3 'TASS Development & Trial Implementation', site surveys were first undertaken to identify suitable locations for installation of the equipment taking into consideration existing access routes and the required oil and power supply connections, and to assess the top and bottom valves of the main transformer tanks. From the measurements taken of the oil valves and existing covering plates, Camlin Power manufactured replacement plates to provide a secure and straightforward connection of the system's oil pipework to the transformers. These plates also included additional valves for direct control of the oil flow to and from the DGA system.

Camlin Power indicated that it should be possible to install the system with the transformers live, however after reviewing the proposals and consulting SSEN's internal operational recommendations, the project team chose to arrange outages to increase safety during work on the transformers. The dates for installation were therefore agreed with the Control Room and the SAP to be present on site, in addition to Camlin Power's installation engineers, and the transformer outages were booked with the Control Room Planning team in line with standard SSEN processes.

Once on site, a POWRA was completed as required for all site work, and the first stage of installation was the attachment of the supporting brackets to the existing concrete structure of the transformer compound at the required location, and mounting of the DGA equipment.

The subsequent connection of the unit to the transformer was carried out during an outage, once the transformer had been switched out and the LOA consent had been issued by the SAP.

Appropriate scaffolding was erected to provide safe access to top oil valve, and the replacement plates for the two valves were fitted. The oil connection between these valves and the DGA equipment was made using flexible piping, with all pipes and connections secured to minimise the risk of accidental damage or oil leaks.

An additional miniature circuit breaker was installed within the tap changer supply circuit to provide a suitably protected power supply to the DGA unit, and the supply was connected to allow initial testing of the unit.

Once it had been confirmed that there were no oil leaks, and that the oil pressure within the unit was stable with all air bubbles removed from the system, the transformer was restored and final commissioning tests were carried out to confirm operation of the DGA system.

In addition, standard oil samples were taken for laboratory testing and comparison with the online DGA measurements.

Following completion of this work, the equipment was fully in service to take oil samples and provide regular DGA readings which can be viewed online by logging in to the secure system via a normal web browser.

6 Scalability & Replicability of TASS

This section considers the factors relevant to the scalability of TASS for wider roll out and replicability of the system for deployment across other network areas.

It is aimed at those considering the implementation of TASS at scale across a given network, and identifies factors relevant to the development of similar technologies, as drawn from project experience to date.

Potential Implications for Scalability & Replicability of TASS

Consideration has been given to the scalability and replicability of the TASS system throughout the development and delivery stage of the project, to support the future potential roll out of this technology.

Key factors which reflect circumstances, characteristics or considerations that have an influence on the scalability or replicability of a solution were identified during SSEN's participation in the European collaborative project DISCERN[16]. These factors provide an assessment framework to highlight where detailed consideration would be of value to ensure the feasibility of scaling or replicating a solution in a different network environment.

Table 5 below applies this framework and identifies the considerations relevant to the development of TASS and similar technologies, as drawn from project experience to date.

The scalability and replicability of TASS will be updated at project closedown in light of conclusions from the currently ongoing trial of the technology. In addition, the stepwise assessment process and cost benefit analysis methodologies created to assess the technical feasibility and financial viability of TASS on a site by site basis will be updated to inform the business case for roll out of the technology.

[16] to leverage the work undertaken in SSEN's NTVV (New Thames Valley Vision) project we partnered in the European Seventh Framework Programme (FP7) project DISCERN (Distributed Intelligence for Cost-Effective and Reliable Distribution Network Operation), which ran from February 2013 to April 2016 - the DISCERN NIA Close Down Report is available on the ENA's Smarter Networks Portal www.smarternetworks.org/project/nia_ssepd_0001/documents, and the DISCERN Final Report and accompanying deliverables can found on the project's website www.discern.eu/project_output/finalreport.html

Table 6 - Factors relevant to the scalability and replicability of TASS

Interoperability - this relates to the level of tailoring or configuration required to allow a device to interact with an existing system	✓ it was known that variations in RTU configuration settings, data semantics, etc., would exist between different substations, requiring the DNP3 data points to be mapped for each substation individually, however the key information available is common across all primary substations and so it was possible to develop the algorithm on that basis ✓ to accommodate this site specific tailoring in a clear way when implementing the algorithm, a distinct DNP3 data point mapping segment has been created in the algorithm within which the correlations between site specific signals and data items used by the algorithm are declared, thereby ensuring that SCADA data received from the RTU are correctly interpreted and commands from the TASS PLC are sent to the correct device ✓ the tool developed to create the TASS DNP3 data point mapping from the existing SSEN Whitebooks simplifies this mapping process and minimises the risk of errors in creating the site specific implementation ! to deploy TASS in other network areas, DNOs or product vendors would need to consider the data points available and requirements for TASS data mapping based on the typical configurations across their network, incorporating different data items or developing ways of simplifying the mapping process as required ! when developing similar new technologies, product vendors should also consider to what extent site or application specific tailoring is useful, rather than adding complexity to the system's implementation, and develop processes to simplify and minimise the risk of errors with any tailoring that is required
Software Design Flexibility	✓ the platform used for the TASS trials provides flexibility in the design and development of software applications, and allowed the TASS control algorithm to be readily implemented and adapted during development ! less development functionality may be required for any control device used to roll out the technology at scale, however any TASS control device used must provide the capability to easily tailor TASS settings and configurations to specific substations, and allow these to be adjusted over time, for example should different timer settings be required or a different crossover point be merited
Interface Design Flexibility	✓ the system developed for the TASS trials supports integration with 1 or 2 RTUs within a substation, with 2 to 4 TASS transformers per primary substation ✓ to allow TASS to interact with existing equipment in the substation, the TASS control device is compatible with SCADA communications over DNP3 ✓ the connection between the TASS PLC and the existing RTUs is via Ethernet cable for DNP3 comms, with power to the PLC provided from the same 24v power supply used for the RTUs ✓ the system developed provides the ability to connect to the synchronising relay via a hardwired connection, via RS-485, or via DNP3 over Ethernet ! a minimum baud rate for data exchange is required for TASS operation - at some locations this requirement may have implications for the substation comms capacity ! though the baud rate used by the algorithm for data exchange is a relative standard rate used commonly across SSEN's substations, the settings at one trial substation did need to be changed to match the algorithm's speed of data transfer, allowing the algorithm itself to remain generic for all substations - an alternative would be to vary the individual algorithm baud rate to match the existing data transfer rate ! substation comms capacity or bandwidth may also be a factor in some locations due to the additional data transfer required to provide comms with the Control Room, however this is not anticipated to be a common issue ! TASS has been designed to return the substation to conventional operation in the event of a sustained loss of comms which means that the Control Room no longer has

	visibility of the substation or TASS system - this functionality was requested by the NMC due to the trial nature of the technology, however once the technology has been demonstrated and verified, this may not be required for future roll out ! the system implemented for the trials uses a count of message signals received by the RTU to monitor comms connectivity with the central Control Room - for roll out at scale, the use of a heartbeat to monitor comms may be more suitable to provide a more accurate indication regarding comms, alternatively, at sites where comms can be more unreliable, changing the TASS setting to allow a longer period of time before TASS responds to a potential 'loss of comms' situation may be beneficial to avoid unnecessary transformer switching ! as a general point for product development to replicate similar functionalities, product vendors should review the range of existing and possible future standards and protocols for communication, data exchange, safety and security when developing all new devices, and consider the number and types of interface ports that may be required for use of the device in different possible deployment scenarios
Modularity	✓ a modular platform has been used for the trial implementation of TASS to provide flexibility when implementing the system in different substations with differing hardware configurations ✓ the I/Os available from the main T300 PLC were just sufficient to provide the required local TASS indications and controls, subject to the use of latching relays to represent both values for binary indications, however additional units could be incorporated to provide additional I/Os if required ✓ the hardware architecture designed for trial implementation includes one switch controller module per transformer to provide sufficient I/Os for a hardwired connection to a synchronising relay, however as it has been demonstrated that the synchronising relays can communicate using the DNP3 protocol, for the wider roll out of TASS the switch controllers could be replaced with an Ethernet switch to provide the required number of Ethernet ports ✓ the wall boxes used for the two initial trial sites can support a maximum of two transformers (allowing the option of hardwired connections to the synchronising relays), however this constraint is primarily due to the envelope of the wall box casing - the modularity of the TASS hardware architecture applied could easily be expanded to accommodate three or more transformers through the use of a larger TASS wall box and additional T300 modules, but with the same connection types (Ethernet & power)
Version Compatibility	*no implications identified*
Addition to the Asset (Device/System) Inventory	✓ minimal new equipment is required to implement TASS - essentially this comprises the wall box housing the TASS PLC, the synchronising relays, and potentially separate online DGA equipment should that be required for wider roll out beyond the trials ✓ for the roll out of TASS at scale all equipment should be individually tagged or labelled, with the location, dates and other relevant information recorded to allow the ongoing tracking and administration of the devices ✓ no implications have been identified to date with regard to any additional inspection or maintenance activities for existing assets, as the additional switching due to TASS falls within the scope of the standard maintenance schedules for individual assets such as transformers, switchgear and tap changers ✓ inspection of the TASS equipment itself can be added as a task within standard substation inspection and maintenance schedules, with minimal implications for resources or time ! increasing numbers of devices to bring enhanced decentralised control functionality to networks may have implications for existing assets with regard to their capacity to accept new pieces of information, therefore when introducing new functionality, such as TASS, existing systems should be assessed to identify synergies and make use of existing devices where possible, allowing additional functionality to be delivered using fewer additional assets to ensure efficient and cost effective deployment

Simplicity/Ease of Installation & Integration	✓ the scheme designed through the project provides a streamlined system for installation and integration with existing assets ✓ the size and weight of the TASS wall box create few issues with regard to space for installation within a primary substation, and no access routes should be affected due to the deployment of TASS ✓ the synchronising relays were installed within the existing switchgear panels at the trials sites, however this is subject to space being available and at some sites it may be necessary to find an alternative location for installation of these devices - transformer protection panels may also provide a suitable location for synchronising relay installation ✓ from the experience to date it's expected that TASS installation activities could be completed in house by SSEN (likewise other DNO) staff should the technology be rolled out at scale ! to integrate the system with SCADA the RTU configuration at each trial site was updated to include the modifications defined in the 'TASS template', requiring the support of the RTS team to upload the template on site in line with standard business processes - similar support would currently be expected for future rollout, however the capability to remotely upload new configurations to such devices would reduce the associated time and cost for SCADA integration ! at present the addition of TASS specific information and commands into the DMS must be done on a site by site basis, with the required template applied by the NMC's Cartographers - for wider rollout it's expected that it would still be necessary to incorporate TASS into the DMS on a site by site basis, in line with deployment at those sites, however with PowerOn Fusion the time taken to add TASS functionality to a substation is not excessive ! where synchronising relays are used it is necessary to update the protection system drawings to represent the inclusion of these devices - for temporary installation during the TASS trial it has been acceptable to annotate printed copies of existing CAD images by hand, scan these and save them to the relevant record folder on the shared area, with printed copies available in the substation, however for permanent deployment it would be necessary to ensure that the digital records are updated accordingly and in a timely manner by the relevant business team
Availability of Alternatives	✓ the TASS algorithm specification was created in a technology neutral manner, such that it could be implemented using a range of suitable alternative PLC devices ✓ in addition to supporting the assessment of TASS for application to other networks or using different devices, this allows the deployment of the technology to be aligned to a DNO's existing procurement frameworks with different suppliers ✓ with continued developments in ICT technology and the industry transition to a DSO world, it can be expected that in time new control technologies will become available at lower costs, and these may include additional devices suitable for the implementation of TASS
Technology Evolution	✓ though the platform used for the TASS trials provides flexibility in the design and development of software applications, for wide scale roll out of the technology it may be possible to incorporate the TASS functionality into an existing substation RTU, or to make enhanced use of a sophisticated control device to provide additional functionality beyond TASS ✓ product vendors may choose to provide the TASS functionality within their 'off the shelf' RTU devices, or incorporate Point on Wave functionality into their switchgear, or indeed develop lower cost dedicated TASS or Point on Wave switching devices
Economies of Scale	✓ as with any technology, economies can be realised when procuring greater numbers for roll out at scale ✓ economies of scale may also be seen as product vendors adopt technology and manufacture more 'off the shelf' devices to meet an increasing demand for a given functionality

	✓ such economies of scale, in addition to competition between different product vendors, will influence the financial viability of TASS and the marginal costs and benefits associated with implementation of this technology at a given site ✓ deployment costs can also be expected to be lower when rolling a technology out at scale than when implementing the technology at a small number of sites, due to efficiencies in delivery
Stakeholder Interaction - this relates to the accessibility of the solution for new or increased numbers of users (or organisations)	✓ a ‘safety by design’ approach was promoted throughout development of the technology, and this principle should be applied for the deployment of TASS in other network areas or development of devices to provide similar functionality ✓ for the trials, while it was essential to provide a good understanding of the technology through the TASS training and briefings, the only key difference from an existing SSEN policy is the requirements to contact the Control Room every time a trials substation is to be accessed - this is in contrast to SSEN’s ‘Access and Entry to a Substation’ process, which holds that where the purpose of entry is of limited scope and for a duration of less than 15 minutes the NMC do not need to be contacted ! should the decision be taken to roll out TASS at scale across the business, or in other network areas, a number of business policy or process documents may need to be reviewed and revised, for example: • the ‘Access and Entry to a Substation’ process may need to be revised to incorporate a change to the ‘15 minute’ substation access guidance • network planning policies would need to incorporate guidance on the application of TASS and identification of suitable, cost effective sites - the stepwise site assessment process and CBA tool created during the LEAN project to assess technical feasibility & financial viability on a site by site basis can be drawn on to develop this guidance, and these methodologies will be reviewed and updated taking into account experience gained through development and trial of the technology, and reported in SDRC 9.7 ‘Network Losses Evaluation Tool’ • work instructions would need to be created should the installation of TASS be brought in house ! for the trials, the project team interacts locally with the TASS system for the purpose of changing settings or downloading data logs, thereby requiring staff to attend site - this is acceptable in the context of a trial, however for roll out at scale consideration must be given to the expected level of such interaction, with capabilities to transfer data via the business’s SCADA system, or remotely access the devices for system updates, introduced where this is expected to be beneficial, and subject to compliance with all relevant secure access and data transfer security requirements ✓ stakeholder interaction also extends to project activities on site to ensure that all Operational Safety Rules and relevant safety and operational processes & documents (inc. competencies & authorisations, PPE, Method Statements, Risk Assessments, etc.) are understood and adhered to by all staff and consultants or contractors involved with the work, and the promotion of safety and compliance with all safety requirements must be central to the application of TASS or other technologies on an electricity network
Technical Abstraction - this relates to the physical characteristics & user experience - i.e. it considers how directly people interact with the technology	✓ whilst TASS provides a fully automated system for switching transformers to reduce losses in primary substations, both Field Staff and Control Engineers need to interact with the system for operational and safety reasons, as such consideration was given to all those who may interact with the technology and how best to design a system that aligns with their expectations and existing activities ✓ the Operational Principles designed into the scheme developed are available to those looking to implement TASS or similar systems, including other DNOs or product developers, to inform decisions on the level of technical abstraction suitable for those applications

Level of Acceptance	✓ the risks and mitigation measures associated with TASS, together with the reasons for developing the technology and running the trials, were fully communicated to colleagues and senior managers during development of the system to provide a clear understanding of the project plans and obtain acceptance from teams across the business of the application of this technology ✓ stakeholder engagement has also been key to the development of a system which fulfils the objectives of TASS while meeting the business's operational and safety requirements, allowing it to be suitable for roll out at scale ✓ all concerns and suggestions raised during engagement through meetings, TASS training sessions and dissemination events were acknowledged and addressed accordingly to promote acceptance of the scheme ! a clear and targeted stakeholder engagement plan should be implemented for the introduction of all new technologies, including the deployment of TASS in other network areas, to: • support requirements capture • ensure acceptance of project or programme plans • coordinate the involvement of individuals from different business teams in project or delivery activities • inform operational staff of the technology and the requirements associated with their roles • raise awareness of the technology and disseminate information as relevant to colleagues across the business ! for roll out of this technology in other network areas, diplomatic communication will be required to promote acceptance of the technology, however the material developed for the TASS trials can be drawn on and adapted to support this engagement
Regulatory and Legal Considerations	✓ the TASS system has been developed to minimise any risks to voltage or security of supply, including CIs & CMLs, and to maintain compliance with Engineering Recommendations P2/6 and P28 ✓ no regulatory or legal barriers to the deployment of TASS have been identified
External Constraints	*no implications identified*
Skills and Training	✓ experience to date suggests that the approach to training taken for the trials can also be used should TASS be rolled out at scale across the business, with the Training team taking on delivery of the sessions ✓ training is required for all operational staff whose roles will be most closely involved with the TASS technology - with regard to the time and resource requirements for this, the training sessions held for 33kV authorised staff and EHV Control Engineers were typically 2-3 hours in duration, with 4-6 Field Staff or 1-3 Control Engineers released from operational duties to attend, and training was held at the depots and office locations which are the bases for these teams ✓ all other relevant staff and contractors may be informed of the TASS technology and trials through briefings provided via Team Managers or through other established team briefing routes ✓ all training and briefing material developed for the trials has been created with consideration to future use should TASS be rolled out across SSEN's network, and in a way that will allow other DNOs to easily adapt it for their own use should they also want to implement TASS ! where the decision is taken to deploy TASS at scale across a network with the installation activity brought in house, additional training would be required for the appropriate delivery teams on the specifics of TASS installation and commissioning, but no additional skills or authorisations should be required - this training can be developed drawing on the experience gained from installation and commissioning during the trials, and with reference to installation guides available from the product manufacturers

In addition to providing a suite of project deliverables of use within the business, the material developed through the project, including the Risk Mitigation Strategy, algorithm specification, training material, signage, etc., is available externally to industry stakeholders, including other DNOs and the regulator, to support others in implementing the TASS technology, and to support the effective development and future operation of similar decentralised control systems and automation solutions as we move to the world of DSO and operate our networks increasingly dynamically.

7 Experience from Project Delivery

This section summarises broader learning points and recommendations drawn from experience during different stages of the project's technology development and trial delivery.

These considerations are relevant to a range of stakeholders from across the industry who deliver or oversee projects to develop similar innovative technologies suitable for deployment across different networks, including DNOs, third party organisations and the regulator.

The work is presented under the following subsections:

- Procurement Plan
- Consideration of IPR Requirements
- Engagement with Colleagues
- Use of SGAM
- System Architecture
- Trial Site Selection
- System Testing and Commissioning
- Condition Assessment and Online DGA Monitoring
- Managing Change in Project Delivery

Procurement Plan

When planning the approach to be taken for delivery of the trial phases of the LEAN project it was clear that a range of skills, expertise and experience would be required in developing and implementing the TASS technology.

As such, to ensure visibility for potential collaborators and allow the most appropriate mix of capabilities to be accessed, the Scope of Works created for the procurement process detailed all elements of the project but set out the requirements in defined work packages. Specific reference to engagement between the work packages was also made to promote strong communication between all relevant suppliers and product vendors.

The structure of this Scope of Works consequently allowed market capabilities to be explored in an open manner, and provided a flexible approach for drawing together and commissioning the different aspects of the trial. This ensured that the work was both well aligned to the project requirements and delivered value across all aspects of the development and implementation of the technology.

A similar approach would be recommended for all innovation projects looking to develop and trial new technology on a network. The LEAN Scope of Works is provided in Appendix A for DNOs and other interested parties to review.

Consideration of Intellectual Property Rights (IPR) Requirements

The prolonged negotiation period for agreeing terms with the consultants selected for involvement in developing the TASS technology occurred despite a draft agreement being issued, and despite the Scope of Works specifically setting out that LEAN is a LCNF innovation project and those expressing an interest in the work must allow the project to adhere to the associated Default IPR arrangements, such that the knowledge generated by the project can be disseminated with relevant stakeholders, including other GB DNOs.

To avoid similar issues on other funded projects, it is recommended that the Legal and Procurement teams of potential consultants and suppliers interested in becoming involved in any such innovation project acquire a good understanding of the innovation governance requirements regarding IPR, and form a strategic view on how best to benefit from involvement in such projects.

A well structured draft agreement, which has been prepared or reviewed by a DNO's legal team prior to issue, is also important as a 'starting point' for discussion on the terms & conditions for procurement.

The negotiations relating to IPR also raised a question as to whether current project governance may create any implications for proposed innovation projects which aim to develop new equipment or devices, particularly where a third party seeks to partner with a DNO to develop or trial an idea for later commercialisation. A similar point was also made during a conversation with attendees at the ENA's Electricity Innovation Forum 'New Technologies and Commercial Evolution' event on 28 June 2018, at which the LEAN project team presented the development and application of TASS.

This consideration relates to the fact that the Default IPR Arrangements contained within the project governance applicable to LCNF, NIC & NIA projects seeks to allow all GB DNOs to use IPR developed through a project. To comply with this, DNO innovation related contracts and procurement agreements include clauses relating to the accessing and licencing of IPR by all DNOs.

While the aim of this approach is clear in maximising benefits to customers, this may raise questions for both SMEs and larger organisations looking to develop particularly unconventional new technologies suitable for wide scale smart grid application - the constraint on third parties from realising future revenue from foreground IP may prevent involvement in such projects, however the perceived risk in developing the technology without the close involvement of a DNO whose participation would need to be supported may lead to a decision not to pursue development.

Clearly, the wide and varied range of innovation projects currently underway within the LCNF, NIC and NIA funding mechanisms demonstrates the appetite for external involvement in such projects, however the IPR requirements may influence some decisions by third parties in choosing to partner with a DNO or in choosing to take an idea forward.

The implications of potential barriers to any research which is of value to the industry, particularly relating to projects focused at the lower end of the TRL (Technology Readiness Level) scale and the development of new devices or technologies, must be considered, with additional and complimentary incentives to deliver such innovation provided as appropriate.

It is acknowledged that it is possible to request a deviation from the Default IPR arrangements from Ofgem, however this must be done through a formal process, and with the requirements and benefits of the deviation clearly laid out.

Engagement with Colleagues

As described in Section 3 'TASS Development & Trial Implementation', engagement with a range of teams from across the business has been required throughout the project to:

- support requirements capture
- ensure acceptance of project plans
- coordinate the involvement of specific individuals from different business teams in project activities
- inform operational staff of the trials and the requirements associated with their roles
- raise awareness of the project and disseminate results as relevant to colleagues across the business

As TASS represents a new way of operating key network assets in our primary substations, it has been important to fully communicate the associated risks and mitigation measures to colleagues and senior managers and obtain acceptance from the business of the application of such technology. A key aim of the project team's engagement has been to allow all suggestions or concerns to be raised and discussed, and make sure all points raised are acknowledged and addressed accordingly.

The Risk Mitigation Strategy created for the TASS trials provides detail on the principles and responses designed into the system to address safety, operational and data security risks, and sets out the roles and responsibilities of various teams across the business during the different stages of the project. Having this as a focus for all aspects of the trial proved exceptionally useful for guiding this engagement, giving visibility as to who had been consulted, and for building trust in and gaining support for the technology.

A clear and targeted engagement plan, supported by a point of focus such as a Risk Mitigation Strategy for guiding the dialogue, recording decisions and ensuring that all relevant stakeholders have been consulted, is therefore recommended for the development and introduction of all similar network control technologies as a valuable means of both informing colleagues and senior managers of the project plans and eliciting their support for a trial.

Alternatively, a proprietary requirements management software tool may be used to detail and trace requirements, however engagement must also be managed to ensure others participate in and contribute to the requirements capture process as appropriate.

In addition to informing teams about the TASS technology, the training sessions run for operational staff whose roles will be most closely involved with the trials provided a valuable opportunity for peer review to verify that relevant factors have been considered and incorporated into the scheme design, and that the system's functionality meets the requirements of our operational colleagues.

Further, the training and briefing material created was also useful for a range of other internal dissemination activities to raise awareness and interest in the trials amongst staff who may need to consider the application of TASS or similar technologies across the business, for example System Planners.

All training activities should be well structured and targeted to specific roles. This is of value in clearly communicating operational and safety requirements, and maintaining a good level of engagement and contribution throughout training sessions. Similarly, appropriate, concise supporting material is welcomed for future reference, and can also be readily shared with others to support wider engagement with the business and other dissemination activities.

Identifying and engaging with all relevant stakeholders is fundamental to requirements capture, and it is important to promote discussion as necessary to reach a consensus where differing view may be held. Innovation teams should aim to manage this thoroughly and in a timely manner as this consultation is of great value for scheme development but also strengthens acceptance of the scheme.

Use of SGAM

As presented in Section 3 'TASS Development & Trial Implementation', an SGAM was created for use in developing the systems to be implemented for the TASS trials and in communicating plans and project requirements.

This model was initially used when engaging with third party service providers and product vendors during the procurement process. It was then subsequently used as a working communication tool during discussions with colleagues from different areas of the business, and the model has evolved as the system design has been refined, with requirements or proposed amendments captured as necessary.

The use of SGAM during the project has demonstrated the benefits of this approach for:

- System Design - when designing systems consideration can readily be given to the responsibilities of different roles and functions of different systems, the boundaries between these, and the data flows required to provide the relevant information to inform decisions, whether automated or manual. It is possible to see where new equipment will interface with existing assets, and identify synergies to exploit equipment for different smart grid functionalities. Additionally, the complete set of SGAM layers support effective collaboration between all those involved in a system's design to elicit requirements and identify all relevant aspects for consideration (technical, functional, data, communications, etc.).

- Procurement - clarity in the specification of complex or interacting systems promotes efficiency in the procurement process, allowing vendors to understand requirements and propose suitable systems or solutions, and supporting the evaluation of proposals by network operators.

Further, the structured and technology neutral nature of SGAM will also support future roll-out of the TASS functionality on other networks as follows:

- Innovation Rollout - by using SGAM to share innovative solutions it's possible for other DNOs/DSOs to analyse and compare solutions, identify and understand aspects suited to centralised or decentralised control on a given network, and assess the adaptations required to replicate a solution on their own networks.

The use of SGAM to develop, analyse and communicate new smart grid technologies and associated business structures is recommended for all similar innovation projects and product development work. SGAM's use in the ENA's Open Networks[17] project to support market reviews and identify new opportunities and business models as we move to the world of DSO and introduce more flexibility to the operation of our networks is also fully acknowledged.

System Architecture

The project team's intention during the tendering process for the trial stage of the project was to implement the system with minimal changes to the existing assets in the substation, and to have clear interfaces between our existing equipment and the trial kit. A design was also sought which could be widely applicable to a range of different substation configurations, with minimal changes required to the architecture or settings for each site. The scheme design subsequently developed and presented in this SDRC report, however, is more streamlined than had been envisaged during the early stages of the project.

Firstly, this demonstrates the value of presenting ideas to the market to invite solutions and proposals from others, rather than creating a very specific design based on preconceptions of what may be possible. Open engagement with markets and potential collaborators is recommended for all similar innovation projects to establish the benefits and constraints of a range of proposed system architectures.

[17] the Open Networks project, led by the ENA (Energy Networks Association), brings together 9 UK and Ireland electricity grid operators, respected, NGOs, Government departments and Ofgem to review and transform the way our energy networks work, and an overview of the project's use of SGAM, including an introductory video, can be found here: www.energynetworks.org/electricity/futures/open-networks-project/future-worlds/future-worlds-consultation.html

Secondly, this highlights the benefit of establishing a clear understanding of the specific functions required from a system at the start of the design process, such that the centralised and decentralised aspects can be appraised, existing systems can be assessed to identify synergies and make use of existing devices and data where possible, and functions can be allocated appropriately to individual components. The relevant information flows and all interface requirements can then be ascertained to ensure that the technology integrates well with existing assets and systems. A similar approach is recommended for the design of all new technologies to bring enhanced control functionality to electricity networks.

The design of the data flows within any system architecture should include consideration of the communications media and number and types of interface ports that may be required for use of a device in different possible deployment scenarios, together with the required standards and protocols for communication, data exchange, safety, and security. In addition to creating a system suitable for extensive application, this will support a straightforward installation process.

Further, consideration of both the trial nature of a project and the future roll out of a technology at scale is important throughout the development process to ensure efficient and cost effective application of the technology. With regard to architecture, this should provide flexibility to the development process and the capability to test and modify the scheme during trials, but identify where adaptations can be made to simplify and reduce costs for wider roll out should the technology be proven successful.

Trial Site Selection

The intention of the TASS trials is to demonstrate the technology developed whilst maintaining SSEN's duty to ensure that there is a minimal risk of supply interruptions. We also have a clear obligation to deliver SDRCs in a cost effective manner that gives customers value for their investment.

As described in Section 3 'TASS Development & Trial Implementation', the trial sites were identified in line with the stepwise assessment process developed during Phase One and taking into account other factors associated with the trial nature of deployment, including the need to obtain sign-off from key senior managers due to TASS offering a significantly different approach to operating a primary substation.

The staged deployment of TASS provides a pragmatic and useful approach to implementing the trials. The initial sites chosen are representative of typical, more 'straightforward', primary substation configurations, allowing factors common across SEPD primary substations to be considered, with the three further approved sites providing more complex factors, such as the network configuration around a primary substation with 4 transformers. The benefits of this approach are that:

- any significant issues with the system can be identified and addressed prior to expenditure on further sites
- risks to security of supply are minimised should any major impacts associated with TASS operation quickly become apparent
- the commissioning team can become familiar with the installation and integration process, and if the decision is made to deploy TASS at further trial sites, this experience can be reviewed and used to improve and bring efficiencies to the delivery process

These factors have supported cost effective delivery of the trials by avoiding excess expenditure until the performance of the system has been demonstrated, and allow those involved with the technology to gain confidence in the system whilst minimising the exposure of the network to potential risks or unknowns associated with the trial nature of the project.

A staged approach to trial deployment is recommended for the introduction of any innovative technology which represents a radical change to conventional network operation.

Section 9 'Conclusion & Next Steps' sets out the considerations with regard to the decision to trial the technology at additional trial sites.

System Testing and Commissioning

It is strongly recommended that progressive stages of testing are used during the development of technologies designed to provide automated control functionality for electricity distribution network assets. This approach allows issues to be identified in a timely manner prior to further development, or more involved stages of testing and full integration with live operational assets.

This subsection summarises the benefits of different stages of testing, and illustrates some of the key challenges addressed during the testing and commissioning of TASS.

Factory Acceptance Testing

Early stage 'Hardware in the Loop' (HIL) testing, as undertaken by Schneider Electric for TASS, allows the interaction of the system and response of the control algorithm to different simulation signals to be tested. The operation of systems that provide real time control capability can then be refined as necessary to de-risk the move to testing in a real environment with connection to external assets or systems.

Bench Testing

Subsequent bench testing in a laboratory equipped with the relevant ICT devices can then be used to test the communications and data exchanges between the different devices. The system or control algorithm's responses to different operational scenarios can also be observed, providing a sense check on the design of the scheme and allowed additional potential scenarios and considerations to be identified and addressed at the development stage.

The TASS test system set up to replicate a real substation environment in SSEN's Protection laboratory proved to be invaluable for identifying issues with the TASS algorithm and with its integration to the existing SCADA and DMS systems, which could then be rectified prior to site installation.

One key example relates to the data flows between the RTU and protection relays, as during testing it was found that the time taken for data exchange between these devices in the event of a loss of supply event was such that the TASS system perceived a lack of data, which consequently caused the algorithm to raise a 'Failed to Operate' alarm and prevented it from switching to restore the transformer. To resolve this, additional checks were introduced into the TASS algorithm to ensure sufficient time was allowed for the PLC to receive all relevant status and alarm signals from the protection system following a supply fault, allowing TASS to safely and correctly initiate the switching sequence to restore the transformer.

Had the issues found during bench testing only been discovered after installation on site, they would have been time consuming and costly to address due to the need to arrange additional outages and schedule resources to complete further testing or commissioning activities.

Commissioning

For commissioning on site, injection and simulation tests can be used to replicate different operational situations and assess the response of the system, prior to enabling the comms link that allows the device under test to issue control signals. For the final stages of commissioning, full automated control can be given to the system allowing it to operate live under the close supervision of the commissioning team.

A detailed commissioning plan must be drawn up to ensure that all relevant aspects are considered and that appropriate tests are undertaken to confirm the correct operation of the equipment, control algorithms and system communications. Any such plan must be created with reference to the system design, the existing assets and systems, site specific conditions, and associated risks. Section 5 'TASS Installation & Commissioning' indicates the range of activities undertaken for commissioning of the TASS scheme.

The commissioning plan also guides the work to ensure that efficient use is made of the time on site, which is particularly relevant where outages are required for installation or commissioning. When scheduling the commissioning activities and resources, it is of course important to allow sufficient time for all aspects of testing to be completed.

As indicated in Section 3 'TASS Development & Trial Implementation', the experience gained from commissioning TASS at the first trial site significantly reduced the time required at the second site. In addition to providing the commissioning team with experience of the system, the approach to commissioning and the issues and challenges encountered were reviewed prior to installation and commissioning at the second site, with the commissioning plan adapted as necessary.

It can be expected that the time required for commissioning any site based system would decrease with the experience gained from additional installations, however a formal review of the process at an appropriate point in time will ensure that the planned approach can be improved accordingly.

Issues Identified During Commissioning

Operation of a system within a live environment will identify further points to be addressed beyond those identified during even extensive bench testing. When commissioning TASS, additional issues with the operation of the system, the associated system communications, and the configuration of existing assets and systems were found and resolved.

One example with regard to the algorithm was that occasionally the TASS system would Disable itself following the de-energisation of a transformer. Investigations revealed that in these instances the TASS system had detected fleeting alarm signals from the 33 kV protection relay, tap changer supply and LV power supply as a consequence of operation of the LV supply changeover scheme, which switches the local auxiliary LV power supply to the live transformer in the event that power is lost from the transformer being used to provide this supply. Though brief, these alarms were interpreted as a protection fault, and the algorithm had responded accordingly to Disabled TASS. To address this and prevent such transitionary alarms from affecting TASS operation, additional time-based filtering was incorporated into the algorithm.

With regard to existing configurations, transformer protection schemes and RTS systems are always designed to the current SSEN standards, however over time both the standards and the devices and their software evolve.

One difference with the MiCOM protection relays at the two trial sites meant that towards the end of commissioning at the second trial site, it was found that TASS failed to open the 11 kV circuit breaker, even though this operation had been completed without issue a number of times before. The cause of this was found to be the fact that for the final stages of commissioning the protection relays were returned to normal service with both telecontrol enabled and the auto-reclose function active on the LVPR, and the auto-reclose function had consequently prevented the protection relay from executing the 'open' command from TASS. To resolve this, additional TASS control signals were incorporated to disable the protection relay auto-reclose functionality prior to opening the circuit breaker, and subsequently re-enable it following restoration of the transformer at a later time. Whilst the same MiCOM LVPRs are used at the first trial site, here the relays run a later version of their software, which excludes this blocking effect.

A second point of interest relating to the protection systems was highlighted during the installation and commissioning of the synchronising relays. The SynchroTeq relay requires a single phase 33 kV voltage as the reference signal for synchronisation, together with 11 kV voltages for each phase for use in the residual flux calculations. Typically within a protection configuration the 33 kV voltage and current measurements are not coupled with the 11 kV voltage and current measurements, and so these measurements are sourced separately for the synchronising relay. During commissioning of the relay at one site, however, it was found that the voltage connections for the 33 kV red and yellow phases within the HVPR panel were incorrect, such that the 33 kV readings did not correspond to the 11 kV voltage readings for these phases. Whilst this does not affect any operation of the protection system, it did present an issue for the synchronising relay calculations and resulted in the Point on Wave switching being 120 degrees out of step with the voltage waveform. This issue with the phases was rectified on site, however it is clear that such checks are required to commission a system providing Point on Wave switching.

Considering the RTS configurations, one difference between the two trial substations relates to the polarity and semantics used for the control disconnection switch - at one site this is data point is ‘Control supply disconnected’, in which case a value of 1 means that the TASS algorithm should automatically Disable TASS, whereas at the other site the equivalent data item is called ‘Control supply enabled’, and therefore the algorithm would need to respond to a signal value of 0. The solution to this was to keep all substation dependent modifications within the DNP3 data point mapping segment of the algorithm described in Section 4 ‘TASS System Design & Integration’, which is inherently substation dependent. This allows the algorithm itself to remain generic for all substations.

One further RTS consideration relates to the fact that it is usual for assets to be assigned identifiers in order of location within the substation. Typically for the transformers, this results in T1 having its LVPR assigned as Node1 and HVPR assigned as Node33, and T2 has its LVPR assigned as Node2 with the HVPR as Node34. This was the case at one of the trial sites, however due to the physical layout of the second primary substation at that site T1’s LVPR is Node1 but the HVPR is Node34, and T2’s LVPR is Node2 but the HVPR is Node33. As such, had this configuration issue not been picked up through the commissioning process, at the second site TASS would have attempted to switch out a transformer by opening the 11 kV circuit breaker of one but the 33 kV circuit breaker of the other, consequently disconnecting both transformers and losing supply to all customers. This was identified by the commissioning team during the injection and simulation tests.

These examples demonstrate the value of putting in place a comprehensive commissioning plan for use at each location where a technology is to be deployed.

Substation and Transformer Condition Assessment and Online DGA Monitoring

The results from the range of substation and transformer condition assessments undertaken to evaluate asset health at the TASS trials sites will be reported in detail in SDRC 9.5 ‘Monitoring & Analysis’.

However, an illustration of the information provided by the online DGA system installed to monitor the transformers during the trials is given in Section 8 ‘Initial Assessment of TASS Performance at the Trial Sites’. This system continues to demonstrate its value in tracking changes in dissolved gas readings, and the SAPIENT intelligent analytics service available with the procured system has been drawn on to help interpret the data and understand the potential reasons for the fluctuations seen. Information from this system is also being shared with relevant colleagues, and there is interest within the business about the use of such enhanced asset health data in the context of better planning maintenance and replacement activities.

As the chosen DGA units have a straightforward connection to the transformers via existing valves, once the LEAN project has concluded it will be possible to remove and relocate the units to other substations to assess specific transformers, and to increase understanding as to how such data relates to or can be used to define health indices.

Managing Change in Project Delivery

As reported in Section 3 ‘TASS Development & Trial Implementation’, a key challenge early in the trial stage of the project lay in agreeing the terms & conditions for procurement with the consultants selected for involvement in developing the TASS technology, Schneider Electric. Once the procurement contract had been finalised, the main challenges were then in coordinating resources and expertise from specific individuals across the business and the need to accommodate their requirements and availability around their primary roles, with many aspects of the project consequently running in parallel. In addition there was a need to reschedule activities due to weather events affecting southern Britain in early 2018.

Ofgem’s decision that their clarified definition of a ‘Material Change’ under NIC project governance[18] should apply equally to LCNF projects, as confirmed to the LEAN project team in September 2017, was therefore valued and welcomed by SSEN as a pragmatic and worthwhile enhancement which allows projects to adapt to challenges and to take opportunities presented during the course of a project.

A shift in the LEAN project timeframe and SDRC report submission dates was raised and presented to Ofgem, with this proposal then accepted and implemented. The significance and practicality of this is clear for gaining learning and

[18] the clarified definition of a Material Change requiring Ofgem’s approval is provided in Appendix 1 and associated Section 8.23 of Ofgem’s ‘Electricity Network Innovation Competition Governance Document v.3.0’, 30 June 2017

delivering value from project expenditure, without the time, resource and cost implications to both Ofgem and SSEN of managing a formal Change Request.

This clarification of governance also allows innovation projects to focus on the key priorities and aims of a project to obtain the learning required to provide useful insight for other DNOs and stakeholders, rather than introduce compromises to meet a timeframe which has no material impact on project outcomes or budget.

For any innovation project it is important to regularly review and assess the implications of any issues on project delivery, timeframes and budget. For funded projects any potential risks and impacts should also be raised and discussed with Ofgem, or other overseeing organisations, at the earliest opportunity to verify that progress continues to be acceptable with regard to achieving the objectives of the project, including fulfilling all SDRC requirements set out in the Project Direction.

8 Initial Assessment of TASS Performance at the Trial Sites

This section presents an assessment of the performance the TASS technology at the two initial trial sites to date with regard to the automated switching activity seen, the associated reduction in losses, and the effect of TASS operation on existing assets.

Observations are presented under the following subsections:

- Data Sources
- TASS Operational Reviews
- Initial Summary of TASS Performance
- Effects of Switching on Power Quality
- Transformer Monitoring and Condition Assessment

Data Sources

A number of data sources are used to evaluate the performance of TASS and identify any potential impacts due to its operation.

Key TASS information has been incorporated into SSEN's data historian system, PI, as described in Section 4 'TASS System Design & Integration'. This data is obtained in real time via SCADA, and graphical representations of the tracked data can be accessed via the business's PI ProcessBook and PI Datalink tools.

Existing business systems, such as PI and the DMS, provide data relevant to assessing the operation of TASS, including network configuration information, status indications and alarms, load information, and substation access and switching schedule records.

Additional data logged by devices within the substations is retrieved manually every two weeks, as this information is not time critical. This comprises the following:

- three log files from the TASS PLC:
  - event log - data points such as statuses, alarms, flags, timers and commands issued
  - fault log - TASS system faults together with a cause for each
  - load data - 10 minute average, minimum and maximum values for load measurements
- inrush current and voltage transient data and waveforms from the disturbance recording functionality of the existing 33 kV and 11 kV protection relays
- inrush current and voltage transient data and waveforms from the synchronising relays

The log files from the TASS PLC provide additional, more detailed information about the operation of TASS to complement the data available within PI. Additionally, they provide a back-up data source in the event that a comms issue temporarily prevents SCADA from acquiring data, and to validate the precise timings of the TASS events where there may have been a delay in the transmission of data via SCADA.

Additional data may also be obtained on request from other systems within the business, such as the RTS comms log which records data flows from the substation RTUs.

TASS Operational Reviews

A number of processes are used to track TASS operation and monitor transformer health at the trial sites. The reviews put in place are designed to allow the project team to:

- monitor the system's response to different operational situations
- assess the business's interaction with TASS
- identify any potential issues with operation of the system
- identify any issues with the transformers potentially caused by TASS operation
- assess any impact on power quality
- quantify the energy saved due to TASS operation to assess the effectiveness of the system

The operation of TASS is reviewed daily, primarily using the PI ProcessBook, with all switching events recorded in the 'TASS event log' created for the trials. The reason for each operation is identified based on available data, and where any causes are uncertain, additional information is obtained from the logs of the devices on site, or requested from other relevant systems used within the business. Here, any specific issues observed through the PI ProcessBook may merit an additional, interim site visit to obtain log data relevant to the associated investigation.

The more detailed data retrieved from the event and fault logs of the TASS PLC is reviewed each fortnight following the site visits. Any abnormalities are noted for investigation, with information added to the TASS event log as relevant, and the data is then stored for reference or future analysis.

The synchronising relays and disturbance recording functionality of the existing protection relays provide information on the current and voltage waveforms seen on difference phases during energisation and switching. This is used to evaluate the inrush currents and voltage variations seen when switching with or without use of the synchronising relay, and assess the impact of TASS switching on the quality of supply.

The online DGA monitoring system described in Section 3 'TASS Development & Trial Implementation' is reviewed on a weekly basis to identify any trends in dissolved gas readings. In addition, the system's alarm thresholds have been set to pick up on any notable changes in measurements from any trial transformer and issue alerts by text message and email to draw the project team's attention to any potential issues. The data can then be reviewed and investigated, drawing on specialist expertise as required, to ensure that any changes which may be due to TASS operation having an adverse effect on the transformers are identified prior to any incident, particularly a loss of supply event, occurring.

The load data logged by the TASS PLC is used to determine the losses saved due to TASS operation. This calculation is based on the transformer specific losses information obtained during Phase One of the project, the substation load profiles, and the information on the times that one of the transformers was switched out by TASS.

Initial Summary of TASS Performance

The initial analysis of the first twelve weeks of operation of TASS shows that the system is operating as expected and is delivering energy savings. At the time of writing, TASS has reduced losses by over 20 MWh in total across the two trial primary substations.

A detailed analysis of the operation, benefits and potential impacts of TASS will be provided in SDRC 9.6 'Site Performance to Date', however this section presents the initial assessment of TASS operation at both trial sites.

The TASS system was activated at both trial sites on 8 June 2018. However, a stack overflow issue within the RTU at Gillingham then became apparent, leading to TASS perceiving an issue with comms availability. The RTU configuration was subsequently corrected, with full TASS operation commencing at Gillingham on 22 June 2018. At each site, once TASS had observed that the substation loading was consistently below the TASS crossover point for the defined 60 minutes, the system automatically switched out one of the transformers.

The first time based (rather than load based) change over event occurred as scheduled on the morning of Tuesday 26 June at Hedge End primary. The Control Engineer on duty at the time kindly emailed the project team to say "I had the privilege of witnessing the first TASS operation this morning!! You probably already know it all seemed to happen seamlessly".

The first load based switching event occurred at Hedge End on the evening of Friday 6 July, with the TASS transformer being successfully restored in response to an increase in load at the substation.

A summary of TASS operation at the two trial sites up to 31 August 2018 is given in Table 5. Here, a 'TASS Switching Event' reflects a full cycle of TASS switching out a transformer and then subsequently reinstating it, whether due to substation loading, a command from the Control Room, or in response to SCADA data or a loss of comms situation. The losses savings are calculated as described in the 'TASS Operational Review' subsection above. Further detail on the performance at each site, together with an indication of the energy used in operating the system, is provided in the text below.

Table 7 - Summary of TASS trial operation up to 31 August 2018

TASS Operation / TASS Trial Site	Gillingham	Hedge End
Commencement of Full Automated Operation	22/06/2018	08/06/2018
No. of TASS Switching Events	T1 x 7, T2 x 7	T1 x 4, T2 x 4
switching due to substation loading	1	3
switching due to time based change over	1	1
switching due to a comms issue	8	0
switching due to a Control Disable command	4	4
No. TASS Locked situations	0	0
No. TASS Paused situations	0	0
No. 'TASS Failed to Operate' alarms	1	1
No. 'TASS Faulty' alarms	0	0
No. 'TASS CoP Error' alarms	0	0
No. hours one transformer was switched out (h of total h)	1638 of 1680	1673 of 2016
% of time one transformer was switched out	97.5%	83.0%
Losses Saved to date	12.90 MWh	10.27 MWh
Value of Losses Saved to date [19]	£ 624.50	£ 497.50
Associated CO_2 Saving [20]	6.49 tCO_2e	5.17 tCO_2e

At Gillingham, the TASS system has enabled one of the transformers to be switched out for almost 98% of the time. This reflects the loading at the substation, with the initial TASS switching operation due to the fact that load was below the defined crossover point, and only one subsequent TASS switching event due to load increasing above the crossover point. In line with this, one time based change over event has been triggered to transfer TASS operation to the alternate transformer following two weeks of continuous operation with one transformer switched out. Four switching operations were due to the Control Room temporarily Disabling TASS prior to someone accessing the substation. Eight TASS operations were then in response to SCADA comms between the substation and NMC being lost for more than 30 minutes. This comms issue has also been identified by the RTS team, who are working to resolve the issue.

At Hedge End, TASS has allowed the site to run on single transformer for around 83% of the time. Here, the load profile increased above the TASS crossover point on three occasions, and one time based change over event has been triggered. Additionally, the Control Room Disabled TASS on four occasions, two of which covered 10 days over two consecutive weeks to allow work to be undertaken at the site. No SCADA comms issues have been experienced at this site to date.

[19] derived using Ofgem's RIIO-ED1 CBA figure for the value of losses of £48.42 per MWh (rounded to nearest 50p)

[20] derived using Ofgem's RIIO-ED1 CBA figure for the 2016 Electricity GHG conversion factor of 0.503 tonnes per MWh

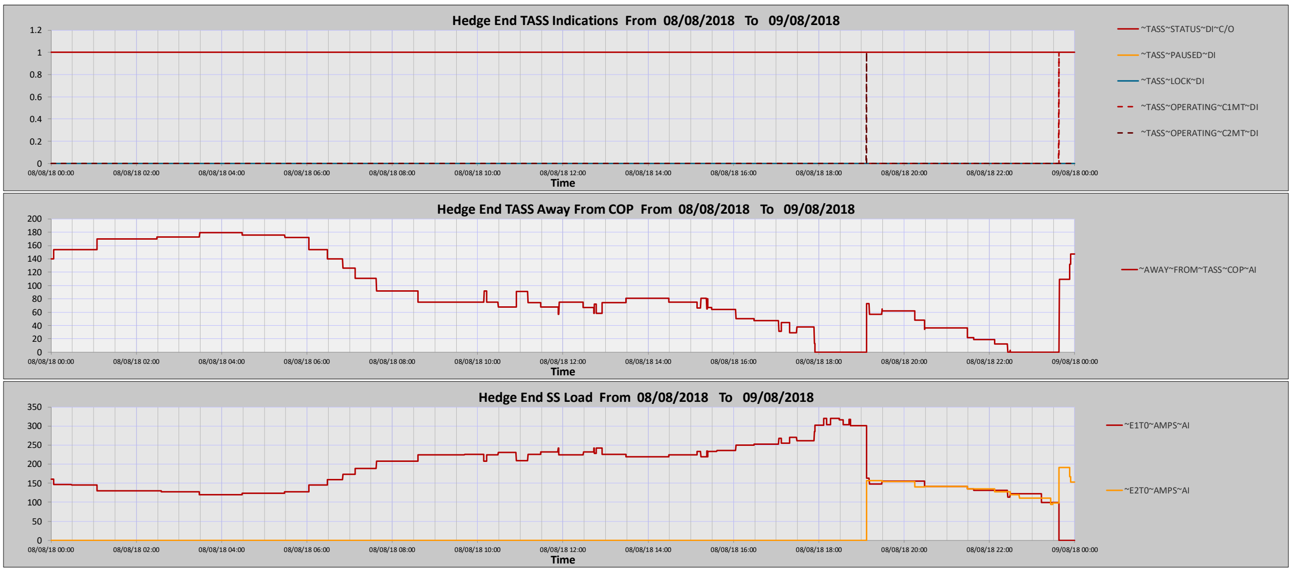
One 'TASS Failed to Operate' alarm has been experienced at each site - at Hedge End this occurred on 7 July whilst switching a transformer out, and at Gillingham it occurred on 11 July whilst restoring the transformer that was switched out. In each case a 'TASS Failed to Operate' alarm was raised in the DMS, and the Control Engineer on duty identified, understood and managed the situation as requested during training, including contacting the project team to inform us and allow us to start an investigation. These events have also demonstrated that TASS was able to quickly identify a problem, Disable itself and raise an alarm as designed.

The investigations have established that on both occasions the issue related to the signal between the synchronising relay and TASS PLC, such that the 33 kV circuit breaker operation had not completed. This is an intermittent problem that had not been experienced during prior switching activity, and work is progressing to understand and resolve the issue. In the meantime, to avoid further such incidents the synchronising relays are currently bypassed by the TASS system. This mode of operation also allows us to obtain valuable information regarding potential impacts on quality of supply without the use of Point on Wave switching.

To illustrate the TASS switching events, two examples are provided below.

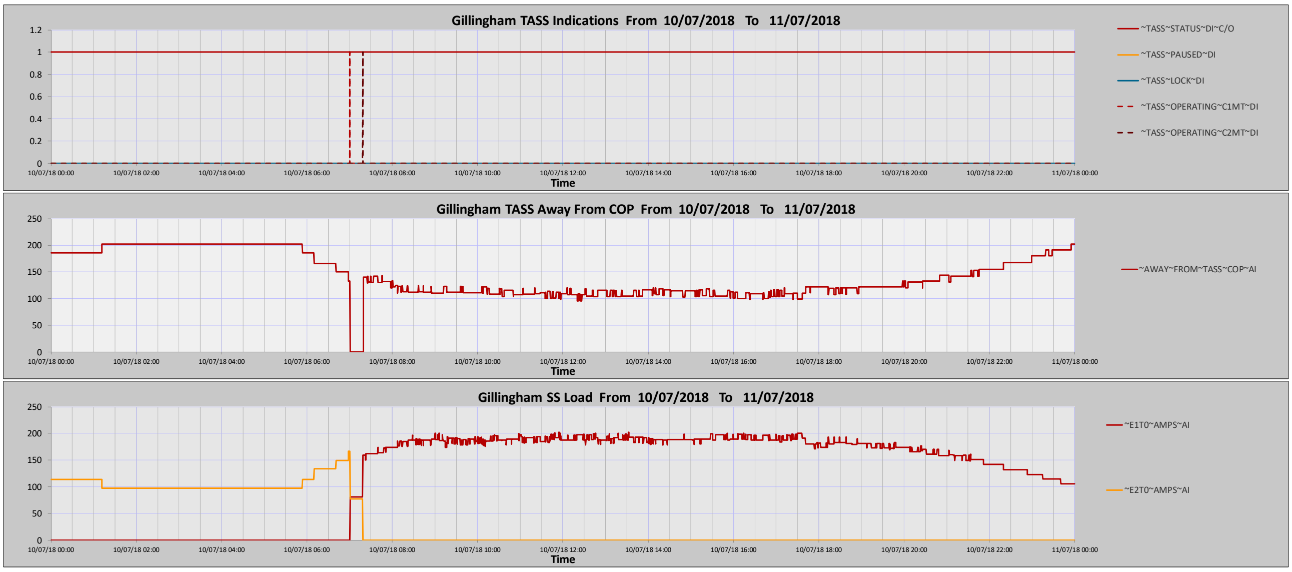
Firstly, a load based switching event at Hedge End is presented in Figure 19. This switching event occurred at just after 7pm on Wednesday 8 August 2018, and it can be observed that 1 hour before the switching event occurred the load on T1 steadily increased to 300 amps (shown by the red line labelled 'E1T0 Amps' in bottom chart) and the signal indicating how far the loading is from the TASS Crossover Point (CoP) (shown by the red line labelled 'Away from TASS COP' in the middle chart) dropped to 0, indicating that the timer for load based switching had commenced a 60 minute count. During that time the load remained above the CoP, and T2 was subsequently restored. Both transformers then stayed in service, however at around 10.30pm the substation loading had again reduced below the CoP thereby commencing the timer count. After 60 minutes of the load remaining below the CoP, TASS de-energised T1 at just after 11.30pm, leaving T2 supplying all the substation load.

Figure 19 - Transformer load based switching event at Hedge End primary substation



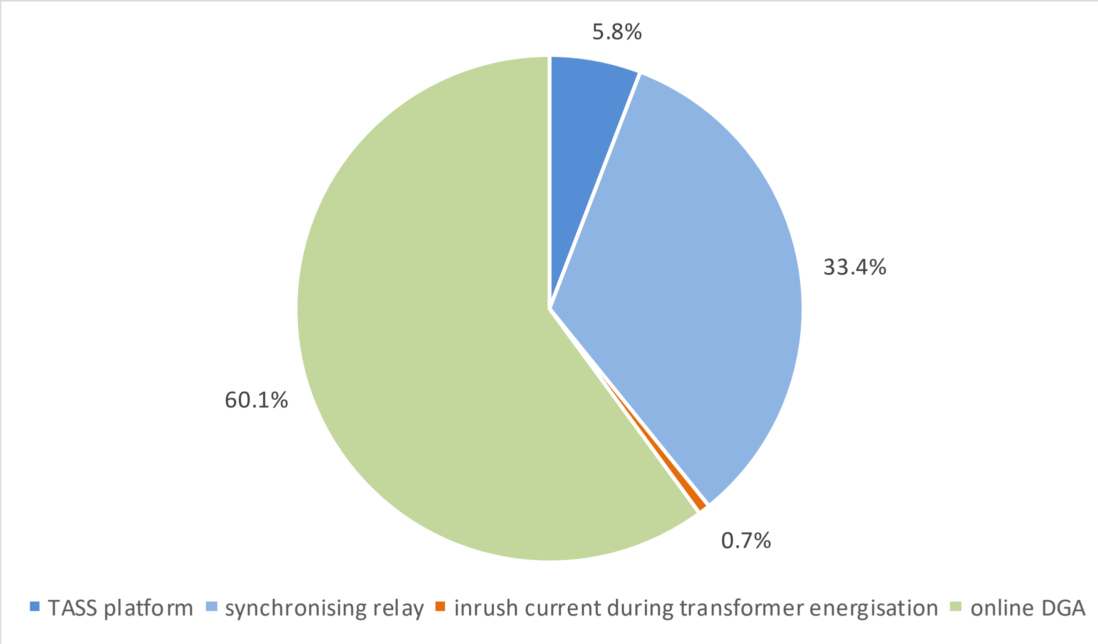
Secondly, a time based change over event at Gillingham is shown in Figure 20. This occurred on Tuesday 10 July 2018 once the TASS had operated continuously on a single transformer for more than two weeks, and commenced as scheduled at 6am (GMT). Before the event it can be seen that transformer T2 is on load (represented by yellow line labelled 'ET20 Amps' in the bottom chart) and that the substation loading is well below the TASS Crossover Point (indicated by the red line labelled 'Away from TASS COP' in the middle chart). At 6am TASS issued a signal to restore T1 (indicated by the first vertical dashed line labelled 'TASS operating C1MT' in the top chart). Both transformers were then kept on load for 15 minutes (as shown by the red and yellow lines in the bottom chart) to ensure that no issues were present. Following this, TASS issued a signal to de-energise T2 (indicated by the second vertical dashed line labelled 'TASS operating C2MT' in the top chart), and the load on T2 dropped to zero with the whole load supplied by T1 (as shown in the bottom chart). TASS remained Enabled throughout (as denoted by the red continuous line labelled 'TASS Status' holding its value of '1' in the top chart), and no alarms were raised.

Figure 20 - Transformer time based change over event at Gillingham primary substation



Considering the energy used by the equipment installed for the TASS trials, the indicative calculations based on the first two months of operation are that the system uses around 8 kWh energy per day. As shown in Figure 21, this energy use is associated with the TASS platform itself, the synchronising relay, the online DGA monitoring equipment and the inrush currents due to transformer energisation. This energy use equates to around 5.4% of the overall energy saving from TASS, or around 2% excluding the online DGA system being used to monitor the transformers during the operational trial.

Figure 21 - TASS trials - proportional energy use



This initial period of TASS operation has provided number of interesting learning points, but importantly this deployment of TASS provides evidence of how this system can be used to reduce technical losses on the distribution network. The energy savings seen at each site to date are in line with the savings forecast using the TASS Tool created during Phase One of the project, though slightly exceeding the forecasts in each case. The TASS Tool will be reviewed and updated taking into account experience gained through development and trial of the technology, and reported in SDRC 9.7 'Network Losses Evaluation Tool'.

Effects of Switching on Power Quality

The inrush current and voltage transient data obtained during TASS switching events during allows the project team to assess any potential impacts from transformer switching on the quality of supply. In addition, this information will allow the effectiveness of the Point on Wave switching functionality provided by the synchronising relays to be assessed with regard to reducing transformer inrush currents.

Here, initial observations are presented, and more detailed analysis will be provided in SDRC 9.5 'Monitoring & Analysis'.

When energising a transformer, the level of inrush current seen varies depending on the timing of the closure of the 33 kV circuit breaker, and relates to the point on the AC wave at which contact is made.

When switching without the synchronising relay, inrush current magnitudes ranging from 0.1 to 2 pu were recorded at Gillingham, and 0.1 to 2.5 pu at Hedge End.

The maximum recorded inrush current at Gillingham substation caused a voltage drop on 33 kV busbar of around 0.6% within the first few AC cycles after closure of the 33 kV circuit breaker. The 33 kV voltage then stabilised within 300 milliseconds following circuit breaker operation. Data from this switching event was recorded by the SynchroTeq relay (though without this device being used to provide Point on Wave switching), and Figure 22 and Figure 23 show the waveforms for transformer inrush current and 33 kV voltage respectively. In the voltage waveform the point at which the circuit breaker was closed is identified by the red circle.

Figure 22 - Gillingham T2 energisation without PoW switching - inrush currents

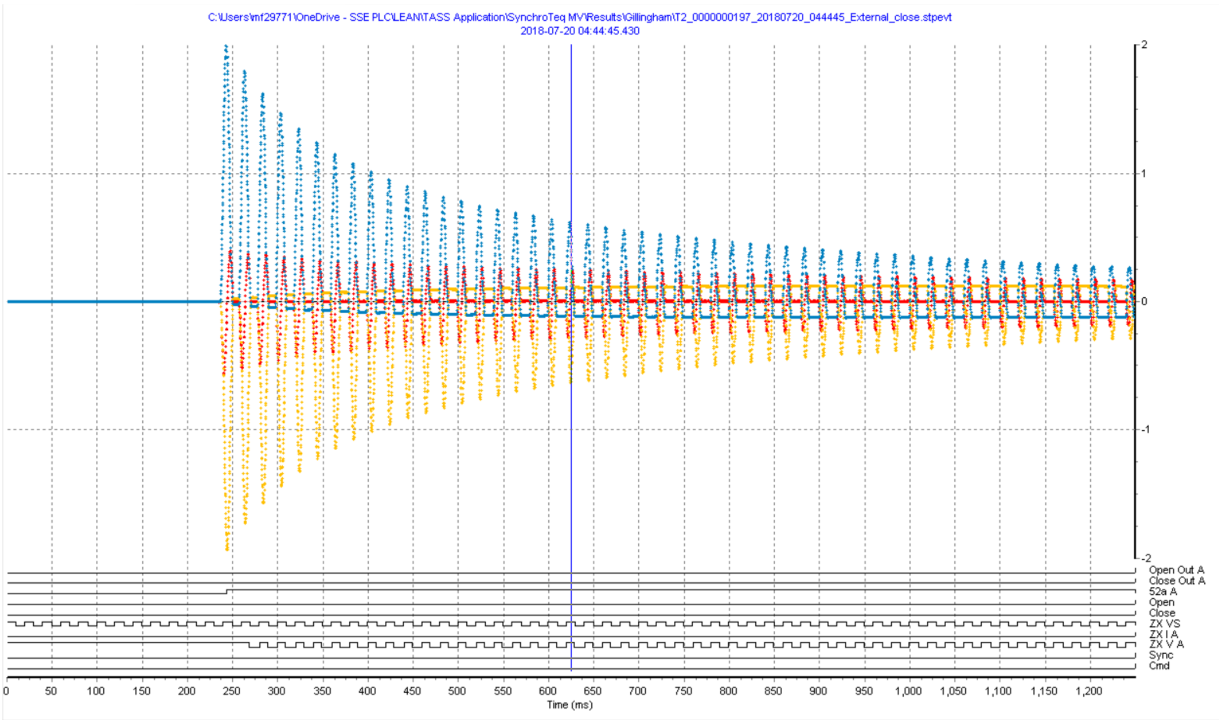
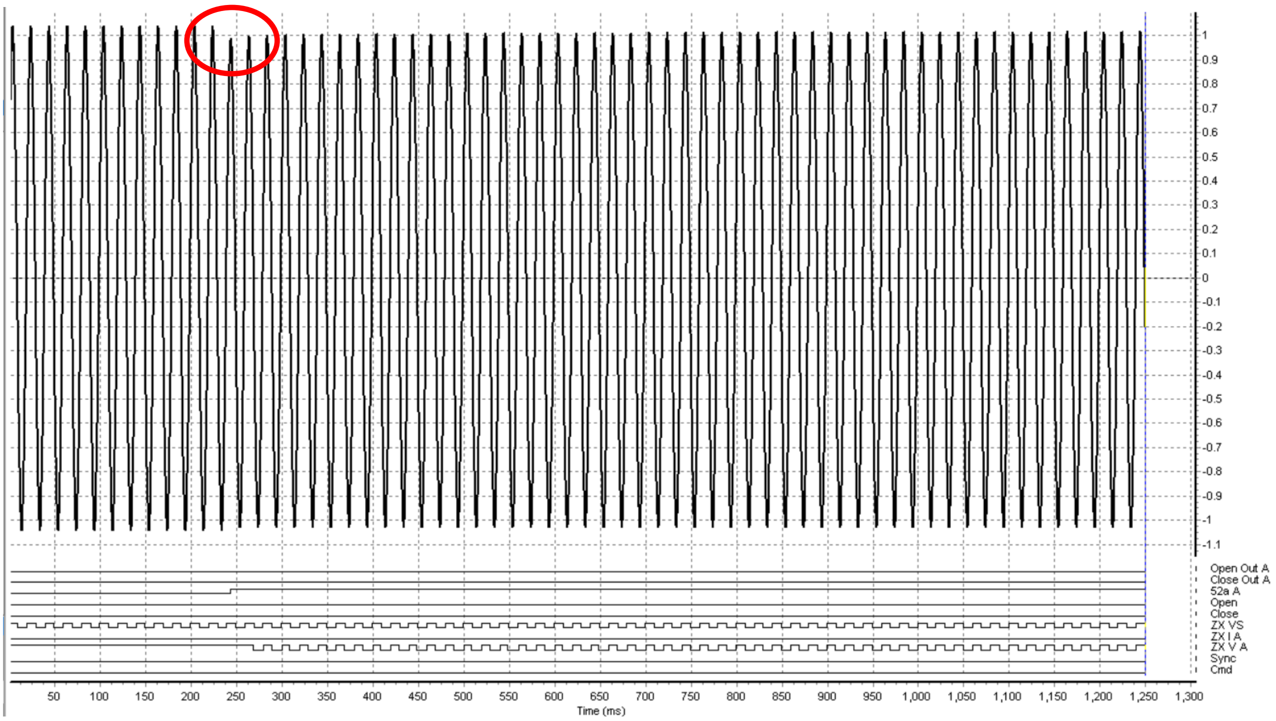


Figure 23 - Gillingham T2 energisation without PoW switching - 33 kV voltage waveform



Where the SynchroTeq relays were used to control switching at a certain point on the AC wave, the inrush current remained within the targeted level of 1 pu, and indeed it has not exceeded 0.5 pu at either trial substation. Examples of the associated Point on Wave switching inrush current and voltage waveforms are presented in Figure 24 and Figure 25 respectively. It can be seen that the impact of an inrush current with the magnitude of around 0.3 pu had negligible effect on the 33 kV voltage.

Figure 24 - Gillingham T2 energisation with PoW switching - inrush currents

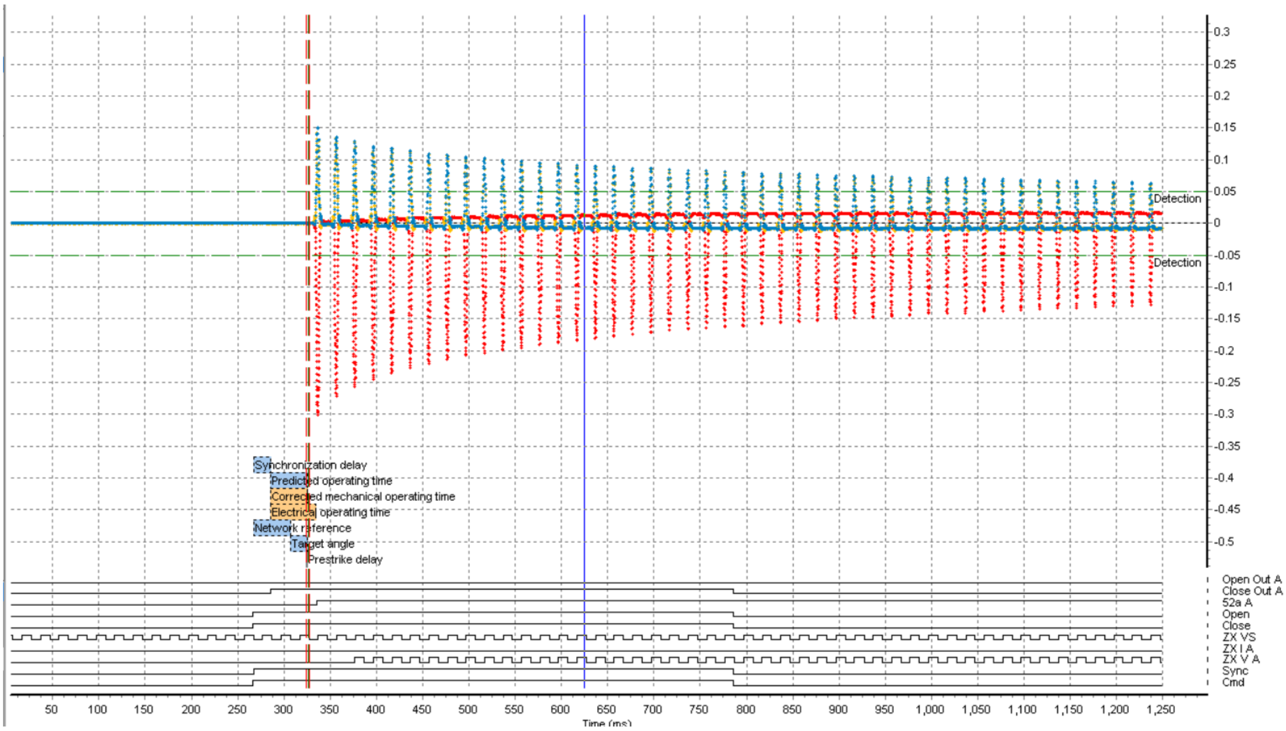


Figure 25 - Gillingham T2 energisation without PoW switching - 33 kV voltage waveform

Considering the 11 kV side, Figure 26 shows the voltage waveform for the same switching event - T2 energisation without Point on Wave switching - as recorded by the SynchroTeq relay. A clear distortion of the 11 kV voltage waveform can be seen immediately after energisation of the transformer. Compering this with the chart in Figure 22, it is apparent that the greater inrush current magnitude on the blue and yellow phases distorts the shape of 11 kV voltage waveforms on these phases, with the smaller inrush current on the red phase having a reduced effect on the 11 kV voltage. As the inrush current decays with time, the distortion of 11 kV voltage passes and this smoothing can be seen in Figure 27, which shows the waveform 1 second after transformer energisation.

Whilst the distortion of the 11 kV voltage waveform seen here is significant, this does not affect the quality of supply to customers as at this stage the 11 kV circuit breaker is still open. Under normal switching (rather than the 'quick restore' used when a loss of supply event has been detected), the TASS algorithm applies a 5 second delay between energisation of the transformer and closing of the 11 kV circuit breaker, allowing the voltage waveform to recover to an appropriate state.

Figure 26 - 11 kV voltage waveform for Gillingham T2 energisation without PoW switching - during energisation

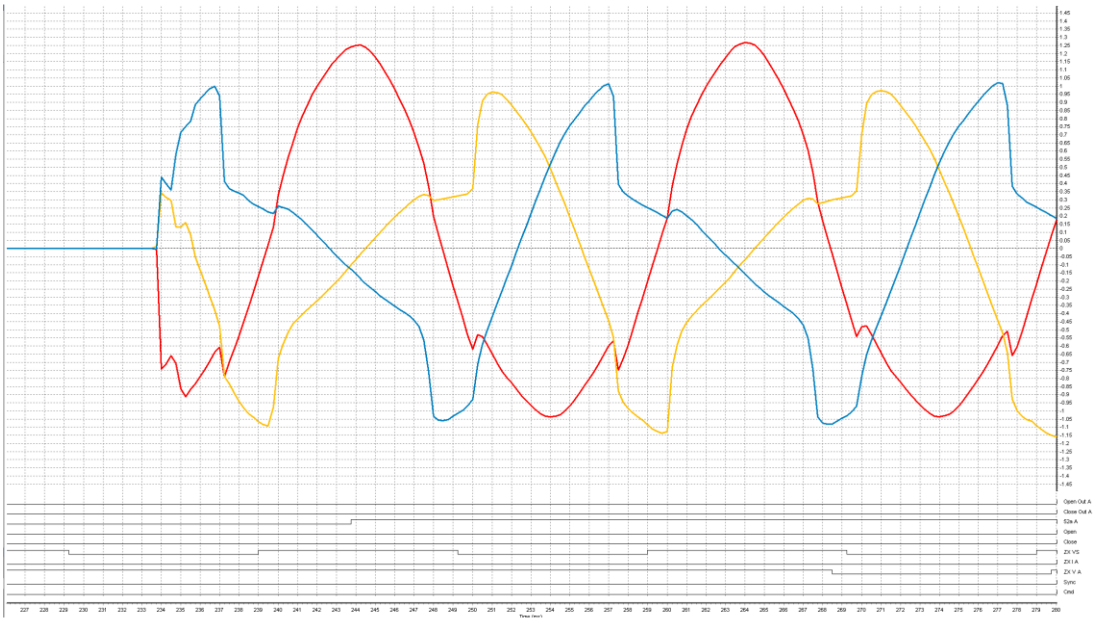
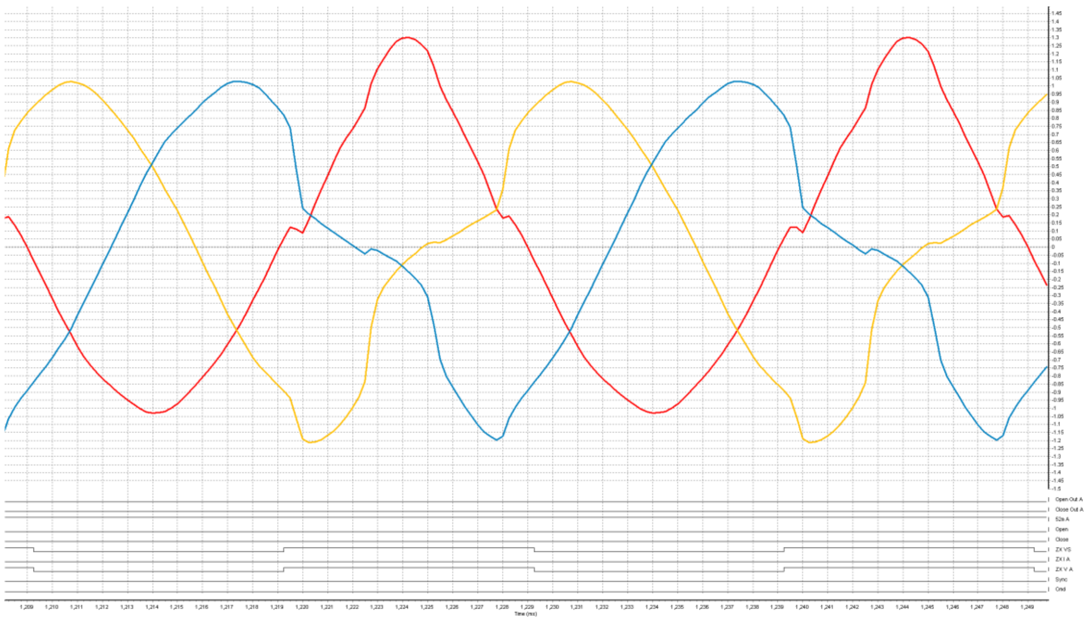
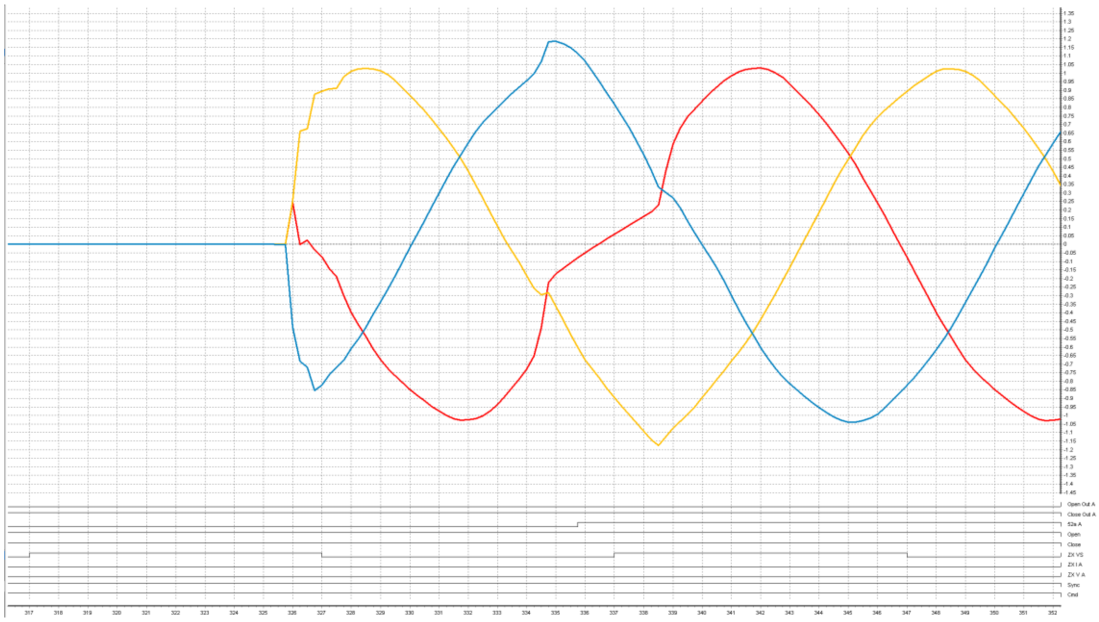


Figure 27 - 11 kV voltage waveform for Gillingham T2 energisation without PoW switching - 1 sec after energisation



The 11 kV waveform from a TASS transformer energisation event with Point on Wave switching is shown in Figure 28. Here, the impact of energisation on the voltage magnitude and waveform is significantly reduced, even immediately after switching, and the waveform recovers within 2 cycles (40 milliseconds). This relates to the reduced inrush currents due to Point on Wave switching.

Figure 28 - 11 kV voltage waveform for T2 energisation with PoW switching - during energisation

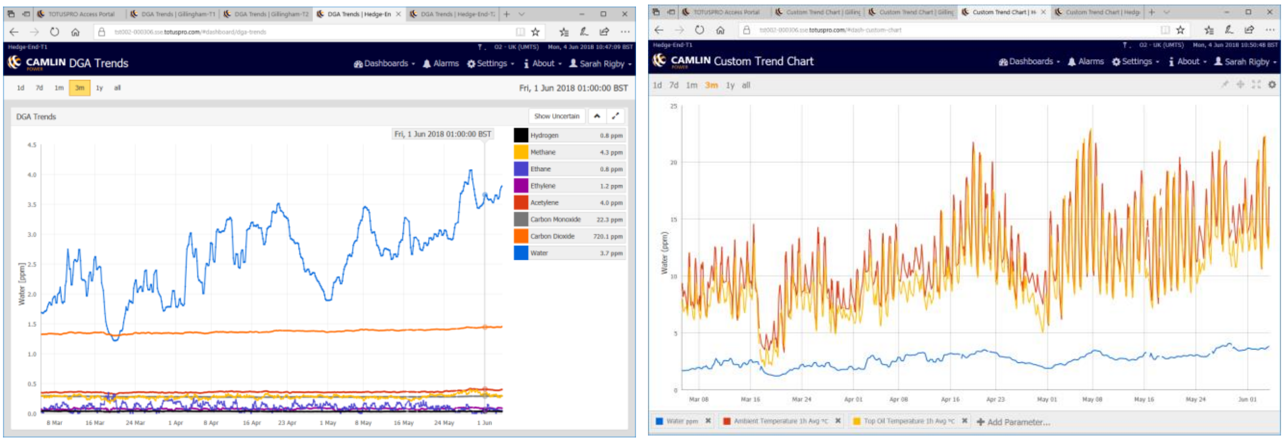


These results demonstrate that Point on Wave switching functionality is very effective in managing inrush currents to ensure these stay at a consistent, acceptable level, thereby resulting in minimal change or distortion to the 33 kV and 11 kV busbar voltages. Without Point on Wave switching the occasional inrush currents of magnitudes up to 2 pu can cause voltage drops of around 1% on the 33 kV busbar, however from the information available to date this impact is seen for a duration of a few cycles before the voltage recovers. The 11 kV voltage waveform is significantly affected immediately after switching, however the voltage recovers prior to operation of the 11 kV circuit breaker. Consequently, for the TASS switching seen over the first two months of trial operation voltages have stabilised before connection is made to the 11 kV network, and so there has been no impact on the quality of supply to customers.

Transformer Monitoring and Condition Assessment

The application of online DGA monitoring will be reviewed and reported in detail in SDRC 9.5 ‘Monitoring & Analysis’, however Figure 29 provides illustrative screenshots from the TOTUSPRO system over a 3 month period from March to May 2018. Though the y-axis in the charts relates to water in these examples, and therefore does not reflect the scale of, for example, the carbon dioxide readings, it can be seen that the gas levels remain relatively stable with some fluctuations through time. The variation in moisture (readings ranging between 1.2 and 4.1 ppm) with ambient temperature and top oil temperature shown in the second chart indicates a correlation between temperature and the migration of water between the solid insulation and oil, potentially also linked to the weather in this region.

Figure 29 - Screenshots from the TOTUSPRO system



The online DGA system being used to monitor the transformers has picked up a steady increase in acetylene readings on one of the trial transformers, with the readings eventually triggering text & email alarms from the system. This represents a curious observation as no significant change has been apparent in the other fault gas readings.

At the time of writing this is being investigated by the LEAN project team in collaboration with operational colleagues and drawing on expertise available through the SAPIENT intelligent analytics service procured with the TOTUS system. Potential causes have been proposed, and the following investigations are being used to examine and understand the issue:

- standard oil samples
- a site inspection of the oil levels and breathers on both the main tank and tap changer to identify anything which may affect the oil pressures and cause or allow deteriorated oil to flow from the tap changer into the main tank
- winding resistance tests

Acetylene readings for both of the Gillingham transformers have always been untypically high, attributed initially to the possible use of regenerated oil to top up the oil levels of the main tanks or tap changer conservators, however since May the readings for T1 have been gradually creeping up - the highest value between Oct 2017 & May 2018 was 10.7 ppm, then from early June the readings gradually crept up with readings peaking at 12.8 ppm in mid August, before then stabilising at around 12 ppm.

As described in Section 3 'TASS Development & Trial Implementation', a number of transformer and substation condition assessment tests have also been used to assess asset health prior to the TASS trials and provide a benchmark or 'finger print' of a transformer so that the same tests can be run during and/or after the trials and compared to identify any changes. Key findings from these assessments will be reported in detail in SDRC 9.5 'Monitoring & Analysis'.

9 Conclusion & Next Steps

This report provides the evidence that SEPD has met the requirements of SDRC 9.4, as set out in the LEAN Project Direction. In line with those requirements, the key topics presented are as follows:

- Development of the TASS technology
- Installation and commissioning of trial equipment at SEPD sites
- Integration of the trial system communications and control functionality with existing assets
- Initial results from TASS operation at the trial sites

Learning and recommendations drawn from project experience and challenges addressed during different stages of technology development and trial delivery are provided, together with factors relevant to the scalability of TASS for wider roll out and replicability of the system for deployment across other network areas.

In addition, the management of risks and opportunities relating to project timeframes is reported. Here, project governance has allowed the project to continue to focus on the key priorities and aims of LEAN and obtain the learning required to meet the SDRC reporting requirements and provide useful insight for other DNOs and stakeholders.

At the time of writing, TASS has been successfully controlling automated switching events for over two months, operating as designed under a range of different situations. The issues identified to date do not raise doubts or uncertainty over the operation of TASS, rather the investigations underway are to provide a better understanding of the interfacing of different devices, and the data used to assess the health of our assets.

Next Steps

Subject to the continued successful operation of TASS, the trials will continue until May 2019.

The system will be closely monitored to track the operational scenarios experienced and evaluate how the TASS control algorithm has responded, allowing any modifications or enhancements that could improve the system to be identified.

The assets and systems that TASS interacts with, including transformers, circuit breakers and SCADA, will also be monitored to evaluate any impacts on these due to TASS operation.

Feedback from operational staff will be sought to understand their experiences of working with the system and identify any changes which would improve the processes for how they interact with the technology.

The decision to apply the technology at one or more additional trial sites will be made once all aspects of the operation and performance of TASS at the two initial sites are shown to be working satisfactorily. This decision will also be informed by the business's experience of TASS, and will be taken in conjunction with the Innovation Steering Board and other key senior managers from across the business.

Two key factors to be resolved at the time of writing, and as presented in this report, are:

- the issue identified with the comms between the TASS PLC & synchronising relay
- the gradual but steady increase in acetylene readings on one of the trial transformers, as identified by the online DGA system installed for the project

Consideration will also be given as to whether additional learning would be obtained from deployment at additional sites, to ensure that any further expenditure is justified.

Knowledge Sharing

Interested parties are very welcome to contact the LEAN project team with any enquiries via lean@sse.com.

The following additional SDRCs will be published over the course of the project as more experience is gained from trial operation:

- SDRC 9.5 'Monitoring & Analysis' - an appraisal of the techniques used to monitor transformer health, and assessment of any impacts on network assets due to TASS operation
- SDRC 9.6 'Site Performance to Date' - a detailed review of the losses savings achieved through deployment of the technology, and evaluation of both the benefits and potential impacts on asset health
- SDRC 9.7 'Network Losses Evaluation Tool' - refinement of the tool developed to allow DNOs to undertake a site by site cost benefit analysis on the deployment of the technology, reflecting experience gained from trial deployment
- SDRC 9.8 'Knowledge & Dissemination' - the project closedown report, including consideration of the deployment of the technology across the SEPD network if applicable

Targeted dissemination activities will also be undertaken with internal and external stakeholders to share information and experience. The material available to other DNOs is designed to support their appraisal of TASS and adoption of the technology on their own networks. In addition, the experience gained through the project can be evaluated by product vendors to inform their development of technologies or functionalities relevant to enhanced levels of decentralised control, automation and monitoring as the industry transitions to the world of DSO with increasingly dynamic operation of GB electricity networks.

Appendices

Note that information such as confidential data and contact details have been redacted from these appendices for publication.

Appendix A	LEAN Phase Two & Phase Three Scope of Works
Appendix B	SGAM for TASS Implementation
Appendix C	Risk Mitigation Strategy - TASS Trials - *redacted*
Appendix D	Information to Assess Trial Sites
Appendix E	Schneider Electric LEAN Project Report_V1
Appendix F	TASS System and Algorithm Technical Specification
Appendix G	TASS Wall Box Design Drawings
Appendix H	TASS Operational Principles
Appendix I	SCADA Data & TASS Responses
Appendix J	TASS Algorithm Flow Chart
Appendix K	TASS Algorithm Testing Specification
Appendix L	Schneider Electric LEAN Commissioning Plan_V1 - *redacted*
Appendix M	TASS Site Testing Specification

The suite of training material (including slide packs and handouts) is available on request by emailing the project team via lean@sse.com.

Enquiries regarding these appendices, this SDRC 9.4 report or the LEAN project in general are also very welcome.