PHOENIX

Project Progress Report 2018

About Report

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Created by	:	Craig Hume	11/12/2018
Reviewed by	:	Michael Walsh	21/12/2018
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Contents

3
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4
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Executive Summary

SP Transmission (SPT), supported by project partners National Grid, the University of Strathclyde and Technical University of Denmark, made a full proposal submission for the project, ***Phoenix – System Security and Synchronous Condenser,*** under the Network Innovation Competition (NIC) mechanism in 2016. Ofgem approved the proposal and issued the Project Direction on the 16th of December 2016. The awarded project budget is £17.64m with duration to 31st May 2021.

Phoenix will demonstrate a sustainable design, deployment and operational control of a Synchronous Condenser (SC) with innovative hybrid co-ordinated control system combined with a static compensator (STATCOM) flexible AC transmission system (FACTS) device, referred to in the project as a Hybrid Synchronous Compensator (H-SC).The use of these devices is expected to mitigate serious system issues that are being encountered on the GB Transmission network as a result of the progressive closure of synchronous generation plants.

The project will enable an efficient composite solution that will enhance system stability and security while maintaining power quality and delivering significant benefits to GB customers.

Project Highlights

This is the second annual progress report for the Phoenix project, covering the project delivery period January 2018 – December 2018, "the reporting period".

The project delivery is in line with the original proposal; however there has been an update with regards to the project programme and resources, which has been highlighted within this report. The most significant SDRCs and updates which have been delivered during the reporting period have been highlighted below:

Work Package 1 - Technology (H-SC Design, Install & Build)

- Report on Engineering and Design Feasibility Studies (SDRC1.1)
- Report on Environmental Studies (SDRC 1.2)
- Report on detailed installation diagrams and site layouts (SDRC 1.3)
- Report on routine and type testing procedures (SDRC 1.4)

Work Package 2 – Live Trial

- Functional specifications for H-SC output monitoring- Methods and User Interface (SDRC 7.3)

Work Package 3 – Commercial & Regulatory

- Cost Benefit Analysis Model for H-SCs (SDRC 2.1)

Work Package 4 - Technology (H-SC Control System and Methodology)

- Report on methods and functional specifications of hybrid control mechanisms to be developed and trialled in pilot demonstration (SDRC 3.1)

Work Package 5 - Research

- Report on study cases and quantification of overall benefits from application of SCs/H-SCs in GB power system (SDRC 5.1)
- Component model adapted to pilot demonstration and for further system studies (SDRC 4.1)

- Report on component level studies from SCAPP project and relevance to pilot demonstration and future installations (SDRC 4.2)
- Report on co-simulation for faster prototyping for new designs and controls (SDRC 4.3)

Work Package 6 – Knowledge Dissemination

- Innovation and Demonstration Workshops (SDRC 8.3)
- Phoenix Annual Progress Report (SDRC 8.4)

Project Risks

It was reported in 2017's Progress Report that Phoenix was suffering from a delay of around six months. This was due to significant contractual negotiations which took longer than initially expected. However, due to the completion of activities in parallel, further review of the programme and the mitigation of risks to the programme we have managed to cut this delay down to around two months. The site work will now begin in the end of January 2019, a little later than originally expected with the Live Trial starting the end of November 2019. We still aim to finish the project by the agreed date during the original proposal.

We monitor risks on a continuous basis with regular review at weekly Project Management Meetings and Monthly Project Team Meetings, as well as regular discussions with all project partners. The key risks are summarised below, with further details in Appendix 2.

Technical Risks

The following technical risks relating to the H-SC Design and Operation have been identified during the current reporting period. Through risk mitigation meetings, we have control measures in place to manage these risks, as well as reviewing them on a monthly basis;

- Failure with Collaboration
- Accuracy of Modelling and the clarification of Studies between each partner
- What if the H-SC model does not work?
- Plant and Equipment Compliance

In order to mitigate and control these risks, SPEN has been involved in early communications with all project partners with SPEN to be involved in review stages of the modelling that has been delivered this year.

Project Management Risks

The following Project Management risks have been identified during the current reporting period. Through risk mitigation meetings, we have control measures in place to manage these risks, as well as reviewing them on a monthly basis;

- Contractual Agreements
- Resource Planning
- Review of Deliverables
- Clarify and alignment of all programmes

In order to mitigate and control these risks, SPEN prioritised the signing of the NGESO contract working closely with the respective legal departments within the first couple of months.

With regards to resource planning, review of deliverables and the alignment of programmes SPEN requested monthly updates from all partners which included a review of the programme and document registers. This information was then aligned on a monthly basis with all other works.

Site Work Risks

The following Site Work & Construction Risks have been identified within this reporting period. Through risk mitigation meetings, we have control measures in place to manage these risks, as well as reviewing them on a monthly basis;

- Risk to ground and soil contamination
- Outages for clearance and proximity works next year
- Collaboration with SPEN Projects Site Works
- Pre-Construction CDM Requirements

In order to mitigate and control these risks, SPEN Projects and ABB worked collaboratively to share the responsibilities for Site Surveys at Neilston including Topology, Soil Investigation and Earthing Study. The results were then shared to avoid repetitive work. After confirming in line with ABB and SPEN Projects programme, SPEN booked outages for cable excavation words early 2019.

SPEN have taken on additional construction resource to assist with the delivery of all Pre-Construction documentation in line with CDM and HSE Regulations which will ensure all documents are in place and there are no delays to Site Mobilisation in early 2019.

Project Managers Report

This section highlights the projects' key activities, milestones, risks and learning over the second reporting period (January 2018 - December 2018).

Project Progress Summary

The significant achievements during the reporting period are as follows:

- After contractual delays in 2017, it was decided to host a formal project Kick-Off meeting in Glasgow in February 2018. This was well attended by all partners and some stakeholders, involving ice-breaker exercises and presentations from all partners.
- SPEN arranged independent Kick-Off Project Meetings with all partners early on in the reporting period. The purpose of this was to confirm each of the partners scope, where we could plan and look ahead to the year;
    - Met with ABB in Glasgow January 2018
    - Met with National Grid in Warwick March 2018
    - Met with University of Strathclyde in Glasgow March 2018
    - Met with Technical University of Denmark, with University of Strathclyde April 2018
- Design Reviews were arranged with ABB where SPEN travelled to Västerås, Sweden in April 2018 for a full Design Review with ABB Engineering Team and then again in late August 2018 where the focus was a review of the Control System
- ABB completed their Equipment Order of the long lead items early 2018, with continual procurement of shorter lead time components throughout the latter half of the reporting period
- In early May 2018, the SPEN Phoenix team held a Modelling & Studies Workshop in Edinburgh with all project partners. This was to ensure the Research Work Package was aligned with all partners knowing their responsibilities and requirements for the Models and Studies
- SPEN and all project partners contributed to a successful Stakeholder Engagement Event which was held in Glasgow in May 2018 in line with the Knowledge Dissemination requirements. This

involved presentations on progress updates from all partners followed by Technical and Commercial Break-Out sessions chaired by SPEN, NGESO and ABB.

- SPEN have recruited an independent Market Specialist with the responsibility delivering the Cost Benefit Analysis alongside NGESO, and chair of the Phoenix Commercial Working Group
- Both SPEN and NGESO held discussions on collating a list of Operating Regimes for the H-SC which was then submitted to ABB to include within their Control System modelling. Some of these Operating Regimes were demonstrated during the Control System Meeting with ABB in August.
- NGESO and the Market Specialist completed the Cost Benefit Analysis (CBA) Model for H-SCs. This will form the basis for the ongoing CBA due to be completed in the next reporting period
- The Market Specialist chaired the first Commercial Working Group meeting which was held in London in September 2018
- SPEN added Construction Delivery resource to the Phoenix Project Team. This involved taking on a Construction Manager in September to engage with ABB and SPT Projects Site Team regarding all pre-construction requirements, and a Site Manager who started in December to engage early about 2019 Site Works.
- In September 2018 ABB Site Team and SPT Site team attended a CDM Meeting in Glasgow where all pre-construction and CDM requirements were discussed. This also involved a second half day meeting where ABB Site Team met with the SPEN Operations team.
- CDM Welfare site has been confirmed for both ABB and SPEN. The site setup to include a 'Knowledge Dissemination Room' which would overlook the construction works. We plan to arrange a monthly meeting in this room for Knowledge Dissemination purposes with both internal and external stakeholders.
- Throughout the reporting period SPEN, SPT Projects and ABB Site Team have attended Site Visits at Neilston. It was then agreed to collaboratively work on the required Earthing and Soil Investigation Surveys in August and September to avoid repetition of works, and the results were then shared.
- All partners have contributed to the writing of this annual Progress Report, with key updates later in the report

Project Administration

During the current reporting period we have held several meetings with each of the project partners, including the first progress meeting with all project partners. We plan to arrange these on a regular basis where we will discuss progress, assess risks and look ahead to upcoming deliverables and collaborative activities.

In order to strengthen the Project Team, SPEN has taken resource from both a construction delivery and consultancy basis with the Phoenix Team now as ***Figure 1***. The Phoenix team at SPEN have weekly Project Management meetings, weekly Design Review meetings and the whole team meet on a monthly basis, or as required. From mid-year onwards we have also started monthly Construction meetings planning all pre-construction elements and preparation for Site Works in 2019.

Project Team Structure

Throughout the reporting period the Phoenix Team has developed in line with the current and upcoming project work package requirements. This maintains our strong position to manage the design, operation, control and construction / delivery aspects of the project.

The Phoenix team has taken on further resource to the Project Team to improve activities relating to Design, Pre-Construction and H&S, highlighted within ***Figure 1*** –

- SPEN Project team has finalised the contract and taken on an independent Market Specialist who will be delivering the Commercial Work Package with NGESO and chair of the Commercial Working Group
- Lead Design role who is responsible for liaising with Engineering Standards and ABB Engineering to finalise the H-SC Design
- Construction Manager who has been responsible for Pre-Construction CDM and HSE requirements, and will be responsible for Construction works next year in line with HSE
- Site Manager who will be responsible for all Site Works next year, including delivery of both H-SC and the new 275kV Bay
- A Synchronous Generation Consultant, who will be responsible for the review of documentation, visits to the factory and the witnessing of the Factory Acceptance Tests (FAT) for the Synchronous Condenser

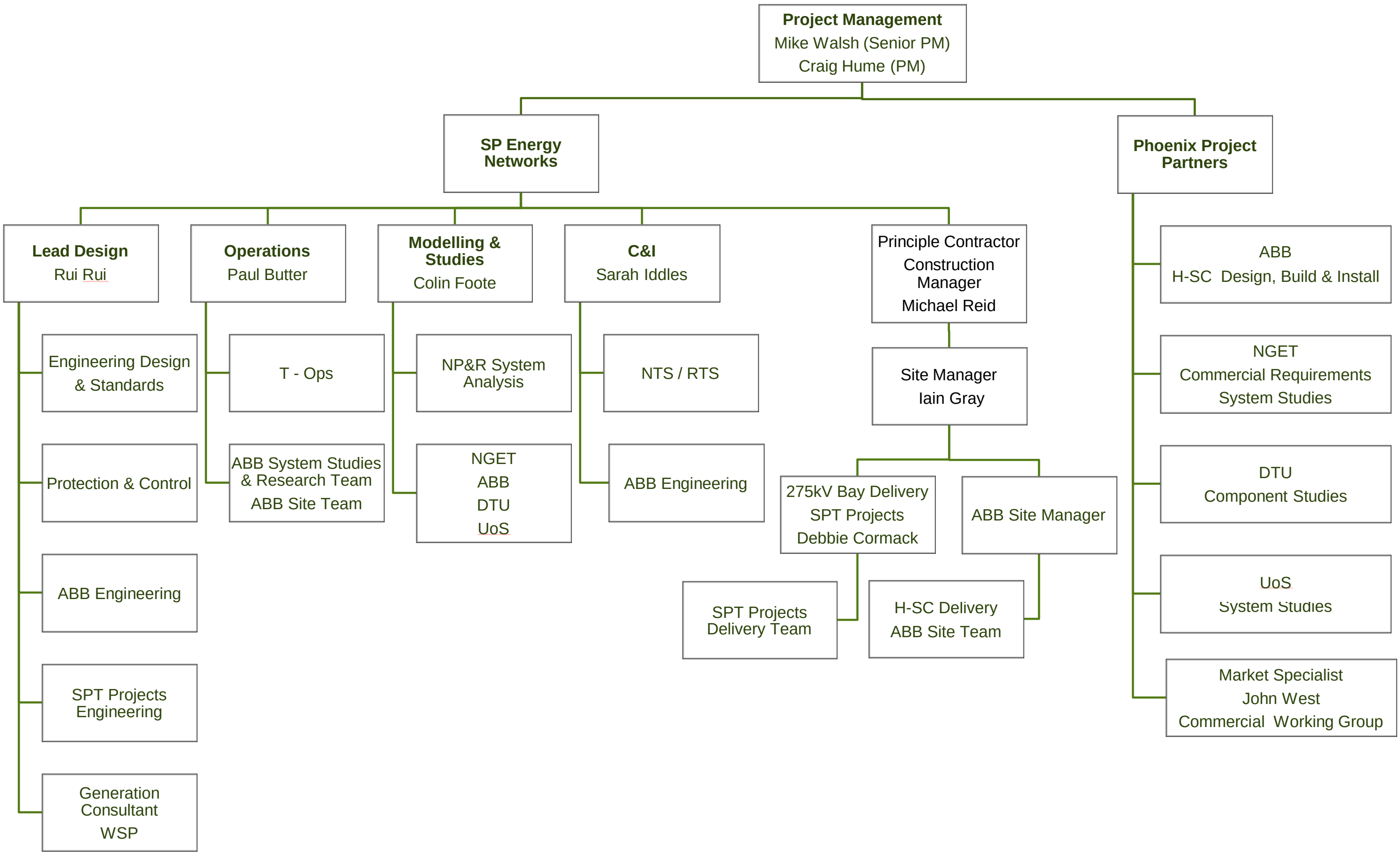

Figure 1 – Phoenix Project Team Organogram

Project Plan

The project comprises of six core work packages. A brief outline of these work packages is provided below:

Workpackage 1: H-SC Design, Install & Build

- Pre-Site Planning and Design
- On-Site Deployment and Commissioning

Following the finalisation of the design of the pilot H-SC installation, including detailed engineering, civil and operational requirements, the plant will be installed and commissioned. Learning generated through this stage will be document to inform future installations.

Workpackage 2: Live Trial

SC and H-SC Performance Monitoring

- SC and H-SC Output Monitoring
- System/Operational Performance Monitoring
- Extended Live Performance Trials Report and Recommendations

The operational performance of plant will be extensively monitored for evaluation against forecasts, in both standalone SC and H-SC modes. Voltage support, short-circuit level and inertia contribution will be validated and fed into financial cost benefit modelling. This stage will also provide feedback to refine system/component models, where appropriate.

Workpackage 3: Commercial Model Development and Roll out Recommendation

- Development of Cost Benefit Analysis (CBA) model for SCs and H-SCs
- Financial evaluation based on economic and emerging energy policies
- Validation of the CBA against actual utilization and value addition of pilot H-SC on the system.
- Regulatory recommendations for future roll-out of SCs and H-SCs

An independent Market Specialist will be employed and work closely with the project team to develop a CBA model to assess the potential services and commercial opportunities available to SC/H-SCs in today's electricity markets and highlight potential regulatory requirements or frameworks required to ensure the GB network can access such services. For example, studies will examine if the application of SCs and H-SCs in different parts of GB system results in similar or increasingly variable benefits for investment considerations.

Workpackage 4: Hybrid Co-ordinated Control and Integration

- Hybrid coordinated control to maximize benefits from different technology solutions
- Lab Simulation of Control Methods
- Hybrid Control method Site Deployment and Testing

Workpackage 4 will demonstrate the innovative control strategies made possible by new hybrid coordinated control methods that maximise different outputs from SC/H-SCs, allowing assessment on the optimum level and variant type (see Section 2.5) to provide necessary system support to inform overall GB roll-out roadmap.

Workpackage 5: Component and System Studies

- Component Level Studies
- System Level Studies

Component models of SC and H-SC will be provided by ABB and investigated by DTU and UoS through a series of case studies, and building upon previous DTU experience. System level studies will analyse the application of SCs and H-SCs at different locations of the GB network and will directly feed into National Grid's FES and SOF studies. Detailed analysis will be performed for specific use cases such as role of SCs/H-SCs in frequency response market in conjunction with fast frequency solution developed through EFCC and potential constraint of western HVDC link in low SCL conditions after planned closure of Hunterston in 2023. The research component of this project will result in GB roadmap for future rollout of SCs/H-SCs and will aid RIIO T2 planning for GB TOs and SO.

Workpackage 6: Knowledge Dissemination

- Dissemination in GB and international conferences and paper submissions
- Quarterly Internal stakeholder events - WebEx and Focus Group Meetings
- Annual External stakeholder events
- Engagement with technical standard bodies and working groups
- Engagement with GB SO for development of commercial mechanisms and participation in working group

Knowledge generated will be disseminated through a variety of channels to all stakeholders to ensure the knowledge generated is shared and considered from a range of perspectives beyond the core project team. Feedback will ensure that any hidden dependencies, flaws or opportunities can be identified and the maximum benefit can thus be extracted from the knowledge generated.

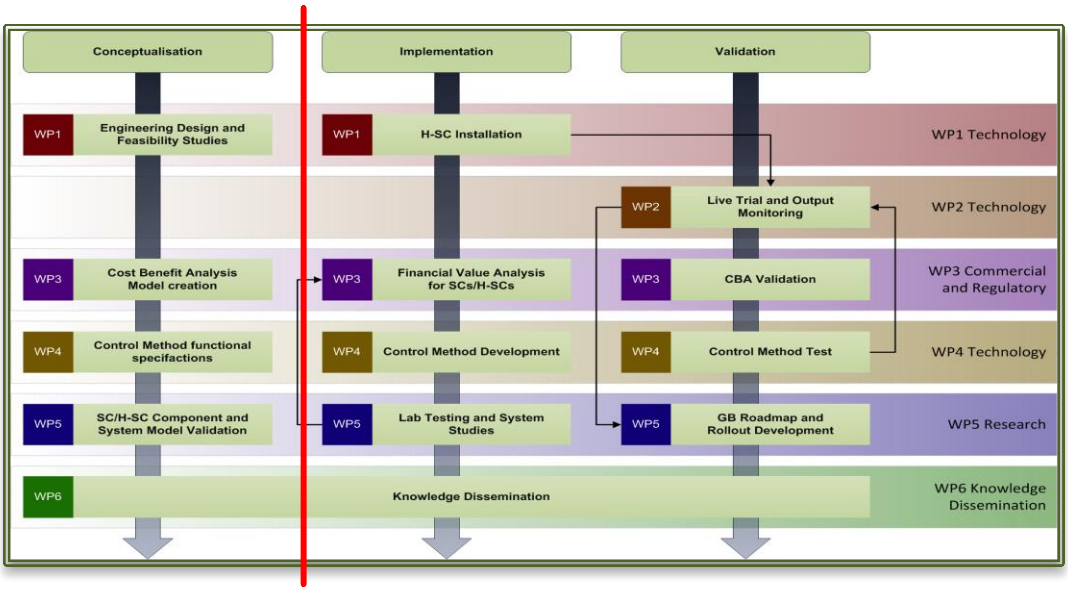

Figure 2 – Phoenix Work Packages

Currently we are coming to the end of the Conceptualisation phase with the next reporting period looking at the Implementation stage, both on site at Neilston and through further development of the Commercial work package in line with results from studies which should be delivered.

The Phoenix Solution

Hybrid Synchronous Condenser Technical Update

The hybrid synchronous condenser (H-SC) solution which will be installed part of project Phoenix is a hybrid system combining a synchronous condenser with STATCOM FACTS devices designed to support the network by offering the following services:

- Boost system inertia;
- Increase the system short circuit level and system total strength;
- Provide dynamic voltage regulation;
- Reactive power injection support to alleviate voltage dip conditions;
- Reactive power absorption to potential overvoltage scenario in light load conditions;
- Investigation into using PSS for PC
- Aid in maintaining power quality of the network.

The detailed design of the H-SC to be installed through Phoenix is nearing completion and, as such, the design is yet to be finalised, similarly to the SC design which is being finalised in the detail design. The current draft version of the single line diagram of the draft H-SC is provided below;

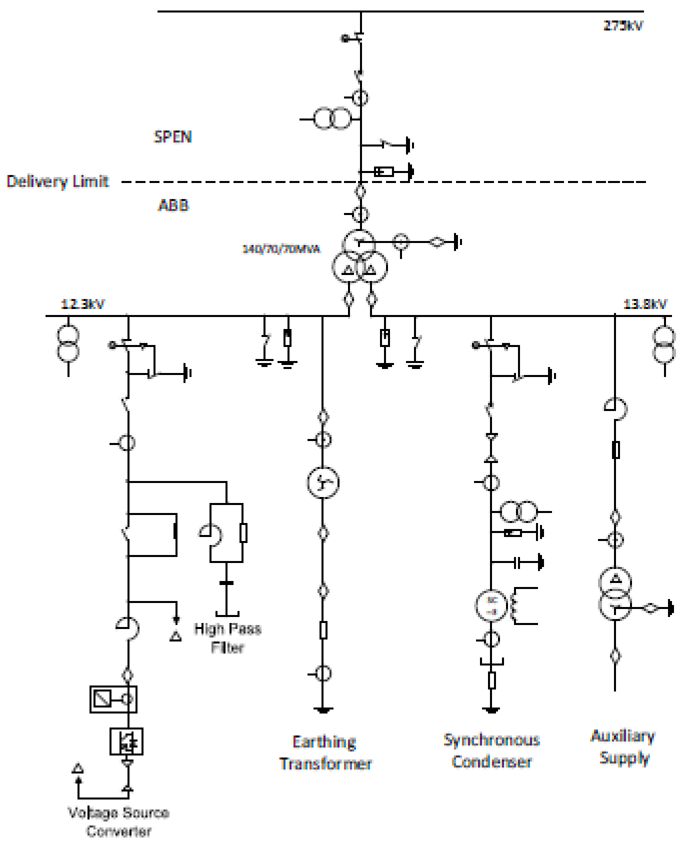

Figure 3 - Single line diagram of the H-SC

The H-SC utilises a fast switching Voltage-Source Converter (VSC) for its fast response and high controllability in combination with the SC with its ability to support the network with system inertia and short-circuit power, and its high overload capability. These two branches of the H-SC are discussed in further detail below.

The Synchronous Condenser Branch

The SC branch comprises of the condenser connected via a busbar to the branch generator circuit breaker along with measurement devices and protection components. The SC is a three phase, synchronous, four pole 50 Hz type with a synchronous speed of 1500 RPM and has been designed to;

- be capable of contributing to system recovery under emergency conditions with transient frequency excursions from 47.0 to 52.0Hz
- absorb reactive power on the occurrence of sudden load rejection or similar event
- provide short-term overload capacitive current at severe voltage sags at the point of connection
- ensure that no critical speed occurs in the range of 80-120% of normal rated speed with the Pony Motor attached

The SC supplied will also achieve the following performance requirements, as a minimum;

- Capable of continuous parallel operation with the UK Grid and contribute towards a stable operation of the Grid
- Remain connected to the Grid over the frequency range of 47.5 Hz to 52 Hz and shall disconnect from the Grid after twenty seconds when the frequency falls below 47.5 Hz and stays above 47 Hz
- The synchronous condenser shall be capable of remaining in synchronism and operating without damage for the above frequency conditions
- Act in accordance with the requirements of the UK Grid Code, complying with the required voltage stability regulations, ensuring harmonics are below the limits
- Capable of rapid disconnection from the Grid without damage under severe Grid disturbance and fault conditions

The STATCOM Branch

The following components are the major part of the STATCOM:

- Modular Multi-Level Converter (MMC) based on IGBT valves
- Air-core design phase reactor
- Electronic Current Transducer with fast response, large bandwidth and capable of measuring DC components
- Charging resistor circuit used for limit the current at energization
- Small high-pass filter in order to mitigate any switching harmonics generated by the converter

The STATCOM consists of a delta connected single block MMC Voltage Sourced Converter (VSC) rated 70 MVA. The VSC is controlled to produce a sinusoidal voltage on the converter terminals. The reactive current injected/absorbed in/from the power system is controlled by adjusting the converter voltage magnitude in relation to the actual MV system voltage magnitude. The required converter current is controlled by adjusting the voltage drop across the total phase reactance connected to the converter terminals, where the total phase reactance seen by the converter is the sum of the voltage drop across the phase reactor and the step-up transformer reactance.

The output current from the VSC is limited by the semiconductor current rating with applicable design margins included. This fact, in combination with the operating principle of the VSC, makes that the device will work as a voltage source when operating within limits and as a constant current source when operating at its limits, providing a reactive output that varies linearly with system voltage.

The VSC branch includes a high-pass harmonic filter. The purpose of the harmonic filter is to minimize the harmonic generation impact from the VSC. The proposed topology consists of one

1Mvar high-pass filter tuned to the 35th harmonic. A damped-filter topology is chosen giving the filter a wider frequency characteristic.

The Hybrid Innovative Master Control System

The MACH™ control system is a microprocessor-based system with a Windows platform that will be responsible for the main functions in the coordinated control of the H-SC. The computing capacity and speed fulfils all requirements for the control and monitoring, and has facilities for remote operation.

It will be possible to run the Hybrid-SC with either the STATCOM or SC out of service. The branches can then be isolated from the system through disconnectors. In such case, the control system will automatically adapt to the H-SC system configuration.

To reduce the possibility of harmful interactions in the system, a three winding transformer is providing electrical distance between the two branches. Studies, which will be performed later within the project, will provide further information about this.

The coordination and monitoring capabilities have the following challenges to be studied during the project.

- Normally a synchronous condenser works also in voltage control mode. ABB has created a master control so that there is only one overall voltage controller for the H-SC, establishing the correct orders to the STATCOM and synchronous condenser control loops.
- Since each branch has its own controller, ABB has put effort on sending relevant and available monitoring/parameters of the machine to the MACH system so that the H-SC monitoring system is implemented at the MACH system (transient fault records, events, alarms, etc.), taking also into account that Neilston substation is unmanned. For this purpose, the communication protocol between MACH system and Generator Control Panel (GCP) has been stablished for the signals that do not require fast communications between the control platforms.

Installation Site

The H-SC will be installed at Neilston 275kV Substation. During the reporting period both ABB and SPEN have carried out several site visits where the survey works were carried out in August and September 2018. The access/egress and transport options from site were also discussed, as well as a full review of the CDM welfare area with ABB Site Management.

Throughout the reporting period, SPEN and ABB have worked collaboratively to carry out the required survey works for their respective site works. Results were then shared to avoid the repetition of the required surveys.

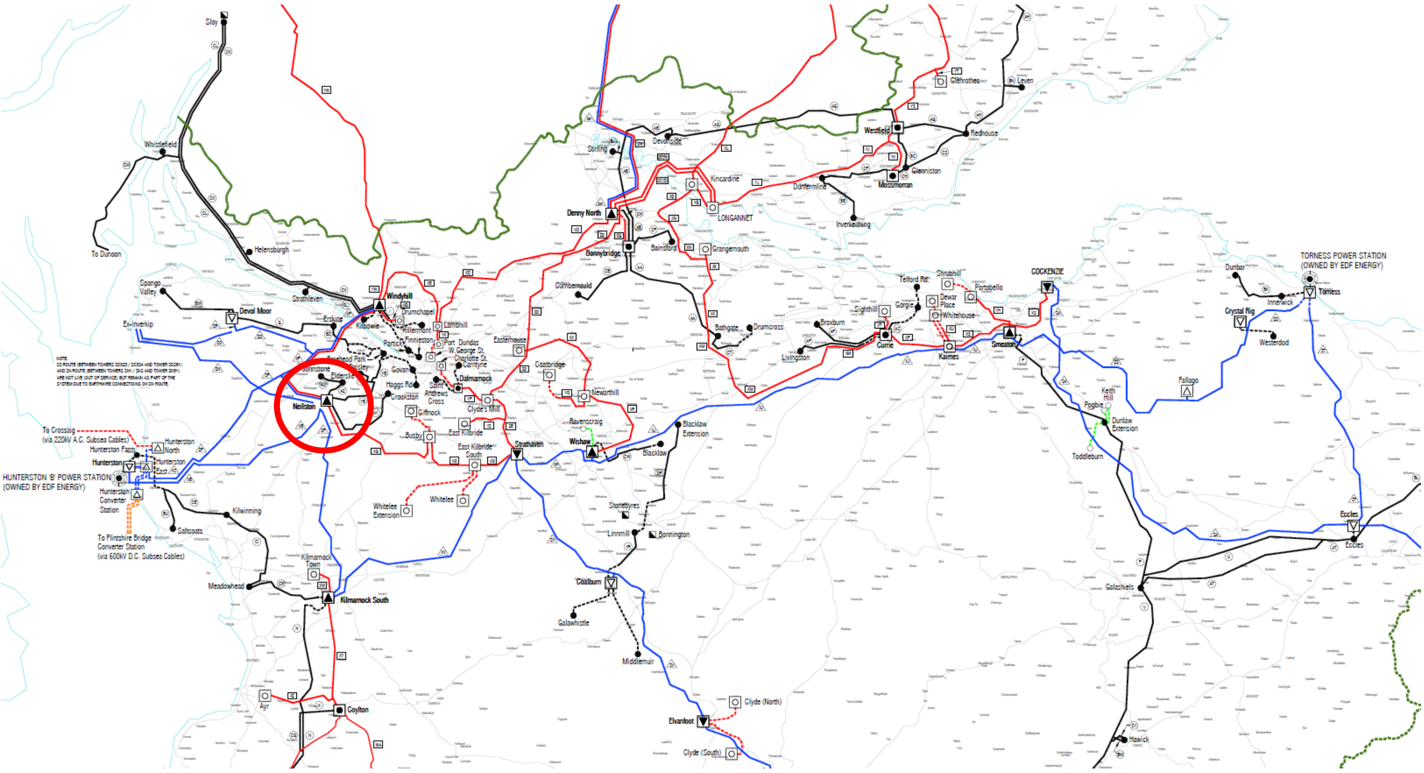

Figure 4 – Neilston Substation in the context of the SPT License area

Figure 5 – Phoenix Installation Site (marked in blue)

Figure 6 – Phoenix Installation Site, showing CDM Welfare Area (marked in yellow)

Figure 7 – Photographs from Site Visit

Commercial Work Package

Introduction

The Commercial Work Package for Phoenix aims to assess and bring forward opportunities for H-SCs and similar assets. This includes work to assess the value that H-SCs and similar equipment could bring to GB consumers through system support services, and work to consider how this value is best accessed in the GB market through options for asset ownership, commercial service development and other approaches.

The commercial work will be informed by wider international experience of similar assets and services and by a Commercial Working Group representing a range of GB stakeholders.

The commercial work plan has been structured to deliver the 7 commercial SDRCs agreed for Phoenix:

- SDRC 2.1 - Cost benefit analysis model for SCs and H-SCs.
- SDRC 2.2 - Report on cost benefit analysis of SCs and H-SCs based on system studies and FES.
- SDRC 2.3 - Report on international application of SCs and benefit analysis.
- SDRC 2.4 - Report on value-evaluation of SCs/HSCs based on pilot installation and performance.
- SDRC 2.5 - Report on impact of SCs/H-SCs on existing balancing schemes and markets.
- SDRC 2.6 - Report on value analysis from roll-out of SCs & H-SCs in GB in future potential sites.
- SDRC 2.7 - Report on regulatory considerations and recommendations for future roll-out of SCs and H-SCs.

The main elements of the work to assess and access value are illustrated in Figure 8.

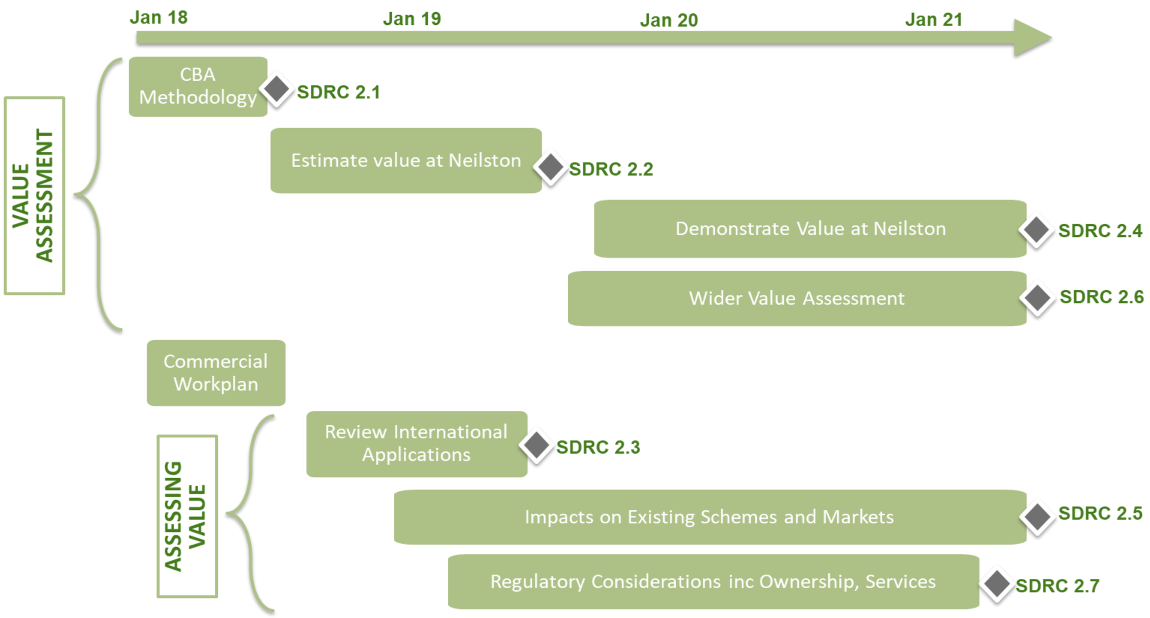

Figure 8 – Main Phases of Commercial Work in Phoenix Project

Progress Update

In order to provide greater definition of the commercial work through to 2021, a detailed commercial work plan was developed between SPEN, NGESO and the Market Specialist and then published in June 2018.

During the current reporting period the following work has been delivered;

- Production of the CBA methodology and completion of SDRC 2.1
- Agreement of detailed Commercial Work Plan
- Establishment of a Commercial Working Group to support Phoenix
- System studies for Neilston (SDRC 2.2)
- Initial international assessment (SDRC 2.3)

CBA Methodology

Work to determine the methodology for the cost benefit assessment, including the power system studies and the economic model, was carried out during the early stages of the reporting period. Key aspects of this methodology include the study approach and tools, the broad range of studies to be carried out, the main assumptions in the value assessment and the H-SC value areas to be tested. A report was then published to detail the approach and deliver SDRC 2.1.

NGESO and The Market Specialist developed a specification for the Cost Benefit Analysis (CBA), which will be used to analyse the benefits of H-SC, this was presented at the Project Stakeholder event in May. Feedback from stakeholders was used to update the CBA specification. The updated CBA specification was then presented at the first Commercial Working Group meeting. The cost benefit approach is illustrated within Figure 9. In short, power system analysis studies are carried out for particular system backgrounds to identify boundary power transfer limits with and without H-SCs and other solutions in place. These limits are used in National Grid's BID3 year round economic tool to calculate constraint volumes over the study period. When other costs including the capital and running costs of particular solutions are factored in, a Net present Value (NPV) for each option is obtained.

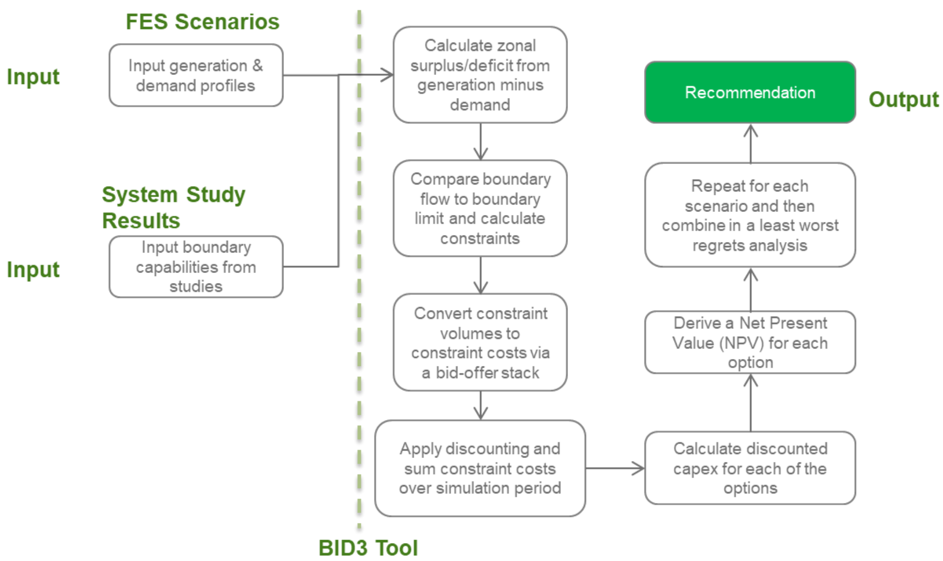

Figure 9 - Flow Diagram to Illustrate Cost Benefit Approach

Commercial Working Group

To enable wider input to the commercial aspects of the Phoenix project, a Commercial Working Group has been formed. This group will shape and review the work carried out on value assessment and on the development of proposed commercial arrangements. It will inform recommendations made by the Phoenix project. The group represents different stakeholder areas as illustrated in Figure 10

Figure 10 – Composition of Commercial Working Group

The Commercial Working Group met for the first time in September 2018. The group is chaired by the Market Specialist. As well as NGESO, the group includes representatives from EDF, Element Power (now Statkraft), Scottish Power Renewables, Siemens, the Energy Networks Association, Electricity North West Limited, the Energy Systems Catapult, Atkins, the Association of Decentralised Energy, BEIS and the Scottish Government.

International Assessment

Whilst there are no H-SCs in service in GB or internationally, the commercial work will be informed by looking at the wider use of similar types of equipment. It is intended that system challenges, synchronous condenser applications, benefits and market arrangements will be reviewed for other systems including Ireland, Germany, Denmark, the US and Australia. This will be achieved through interviews with relevant SOs, project developers, OEMs and regulators.

The work is drawing on project partners, Commercial Working Group members and wider contacts for input on international projects. To date, interviews have been carried out with system operators including Energinet and the Australian Energy Market Operator, OEM's including ABB, Siemens and GE. These have reviewed a number of different synchronous condenser applications and also variants of synchronous condensers that are available. The international assessment will continue through to June 2019 with a set of interim milestones in place to help deliver the work.

As well as a report identifying the learning that can be taken into the Phoenix project, the output of the international work will include interview records, case studies and Commercial Working Group conclusions.

Research and Studies

System Studies

NGESO carried out initial system studies to analyse the benefit of SC at Neilston 275kV, using the GB transmission system dynamic model (developed by NGESO) and the SC generic model provided by DTU. The benefit has been analysed by carrying out boundary transfer capabilities between England & Wales (E&W) and Scotland for different scenarios, with and without SC. These system studies include thermal, steady state voltage, fault level analysis and stability analysis. Currently system studies are in progress to define the benefits of SC, with rating of 140 MVA at Neilston 275kV location.

Initial studies have also been conducted by UoS using the same SC and STATCOM models which were delivered by DTU, focusing on Zones 01-06 in the GB network as illustrated in Figure 11. In order to investigate how SCs and STATCOMs can support the network operation during disturbances, faults have applied to evaluate the system's performance under the following conditions:

- SCs with a capacity of 70 MVA are installed gradually from Zones 01 to 06 (e.g. firstly 70 MVA in Zone 1, then 70 MVA in Zone 1 and another 70 MA in Zone 2, etc.);
- SCs with different capacities from 70 MVA to 420 MVA are installed in Zone 01;
- STATCOMs with a capacity of 70 MVA are installed gradually from Zones 01 to 06 (e.g. firstly 70 MVA in Zone 1, then 70 MVA in Zone 1 and another 70 MA in Zone 2, etc.);
- STATCOMs with different capacities from 70 MVA to 420 MVA are installed in Zone 01;
- SCs and STATCOMs with different capacities from 70 MVA to 420 MVA are installed at the same time in Zone 1.

The objectives of the above System Studies are:

- To familiarise the operation of the developed models and validate their performance against the design specifications;
- Initial comparison of the capability of SCs and STATCOMs in providing reactive power and voltage control support during faults;
- Initial investigation of the impact of locations of the SC and STATCOM units in relation to the fault locations on the voltage support performance;
- Initial investigation of the impact of different capacities of the SC and STATCOM units and the combination of the two types of units on the voltage support performance.

From the studies conducted, it was found that SC and STACOM units are both capable of supporting the voltage during faults. Specifically, the level of voltage dip (during fault) and overvoltage (after fault clearance) could be significant improved with the SC and STACOM units. It has been observed that by increasing the capacity of the units, both under- and over-voltage levels can be better-regulated. In the studies, it was also found that the locations of the units do not appear to have significant impact on the voltage recovery performance. However, this could be due to the fact that the SC and STATCOM units are located in relatively close locations. Future studies will investigate wider geographical locations to evaluate the impact of the units' locations and capacities on their effectiveness of providing voltage support.

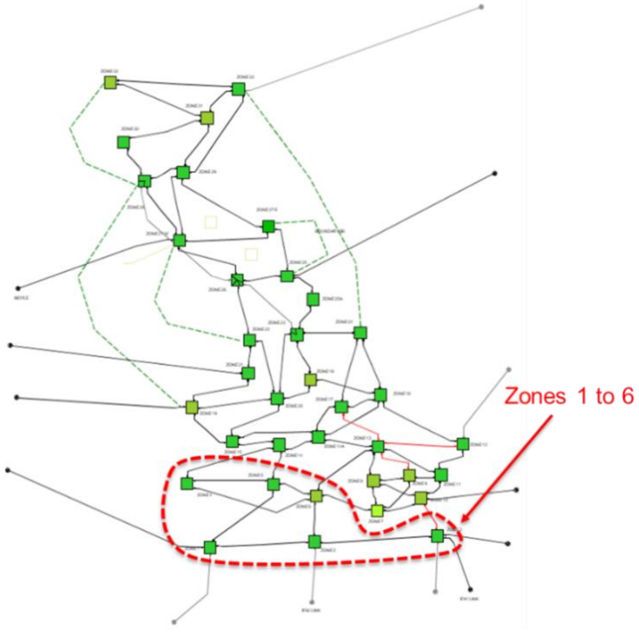

Figure 11 - GB network model in Power Factory highlighting Zones 01 - 06.

Component Studies

DTU has been working on the component studies and the control models of a synchronous condenser and a battery energy storage system. The components were modelled in a PowerFactory simulation platform, and basic initial performance evaluation tests were carried out.

Synchronous Condenser

The synchronous condenser model that was delivered to DTU by ABB (built in PSCAD) was used as a reference to validate our PowerFactory model. DTU have demonstrated that the two models' responses are closely aligned. The PSCAD model did not include overexcitation limiter (OEL), so DTU built a model of an OEL based on the specification of the machine. The PSCAD model was also lacking a step-up transformer, so a generic model was added together with a transformer impedance compensator in the synchronous condenser control. The report summarizing findings on synchronous condenser has been delivered to all project partners.

Battery Energy Storage System (BESS)

The BESS model consists of the component and the control model. The model of the battery is based on an equivalent circuit shown in Figure 12.

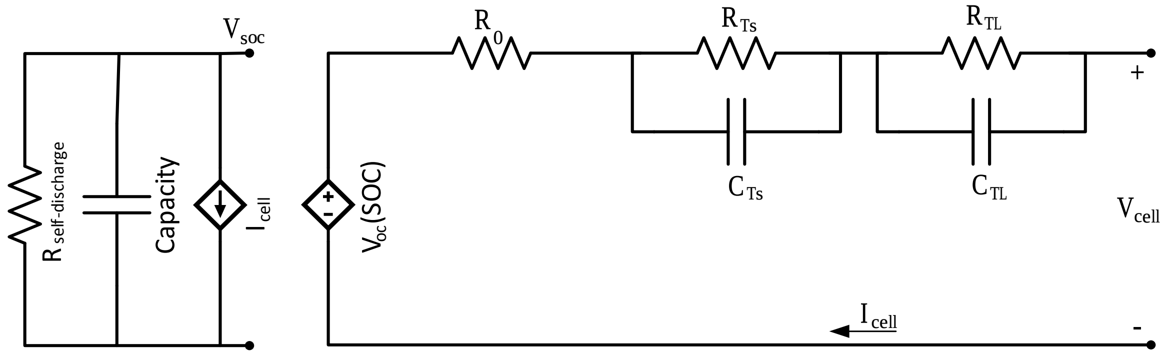

Figure 12 - Equivalent Circuit of a Battery

The elements in the model represent different chemical phenomena within the battery. R0 is the internal resistance of the battery, and it represents the immediate voltage drop at the battery terminal when the battery is loaded. The RC circuits represent two distinct processes:

1. R_{Ts} and C_{Ts} model the resistance due to the charge transfer and polarization and double layer capacitance existing on the interface between an electrode and the surrounding electrolyte; in the literature, this process is also referred to as the short-term dynamics.
2. R_{TL} and C_{TL} represent the concentration polarization resistance and capacitance; this process is often referred to as the long-term dynamics.

V_{OC} is the internal voltage of the battery, and it represents the open circuit voltage at the battery terminal. $R_{self\text{-}discharge}$ characterizes the loss of charge over a longer period. This parameter is not relevant for short-term studies, because the loss of charge is negligible (usually up to 5% per month), and consequently it was not taken into account for the model.

The mentioned parameters are all dependent on the state of charge, temperature, and to some extent on the rate of charge/discharge of the battery. In the two models that we provide, only the parameter dependence on the state of charge was considered, because this model is only a basic, generic representation of a battery system.

The complete model consists of control and component models. The controllers that are implemented include frequency controller, active power controller, voltage controller, as well as battery charging controller. An important aspect of the battery charging control is to keep the battery voltage within the permissible range, in order to protect the battery from thermal runaway, and prolong battery lifetime. This type of control is known as the constant current-constant voltage (CC-CV) battery charging. Figure 13 illustrates the operating principles of this method.

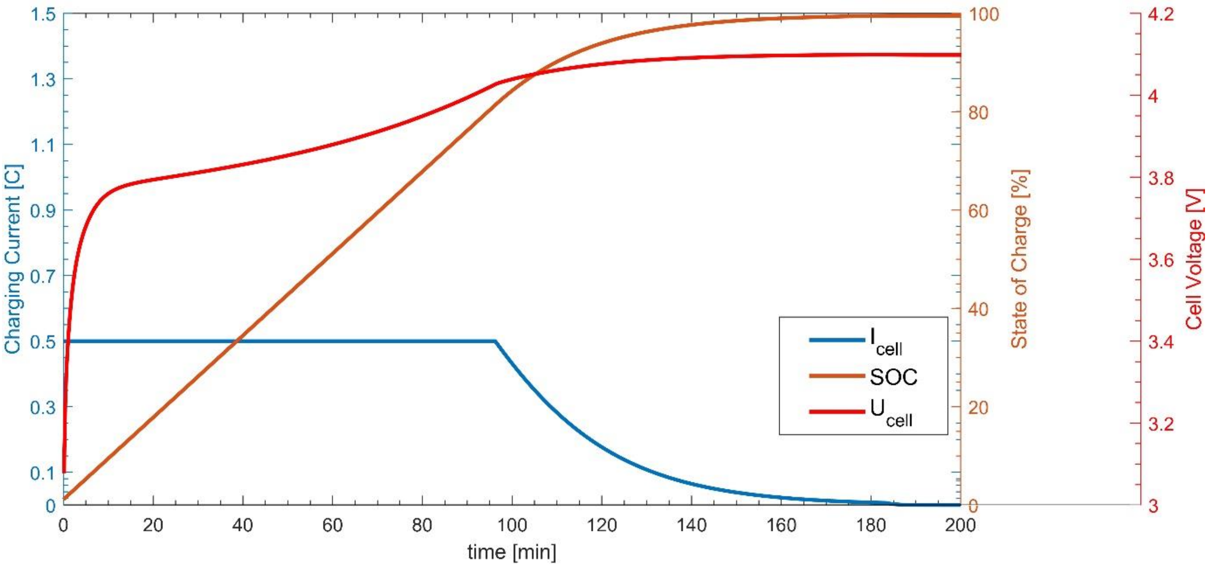

Figure 13 - Constant Current – Constant Voltage (CC-CV) Battery Charging Method

The model provides four basic functions:

1. Frequency droop control.
2. Reactive power support.
3. Charging and discharging of the battery in intervals; changing active power set point.
4. Fault ride-through capability.

The single line diagram of the system is shown in Figure 14.

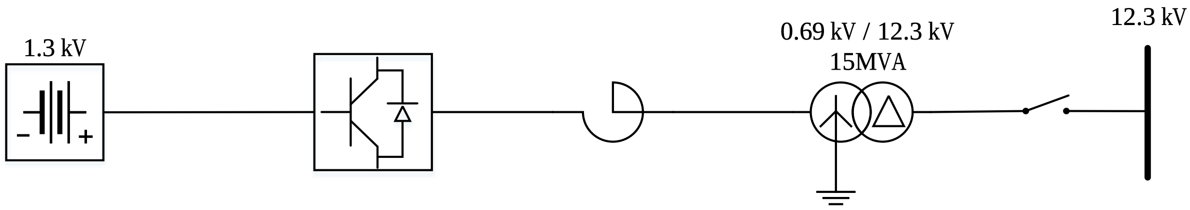

Figure 14 - Single Line Diagram of the Battery Energy Storage System (BESS)

Figure 15 is a demonstration of the battery response during charging and discharging, where the active power set point was changed to 1 pu, and -0.5 pu, respectively in order to show the charging and discharging process. The report delivered to the partners in the project contains demonstrations of other BESS model functions.

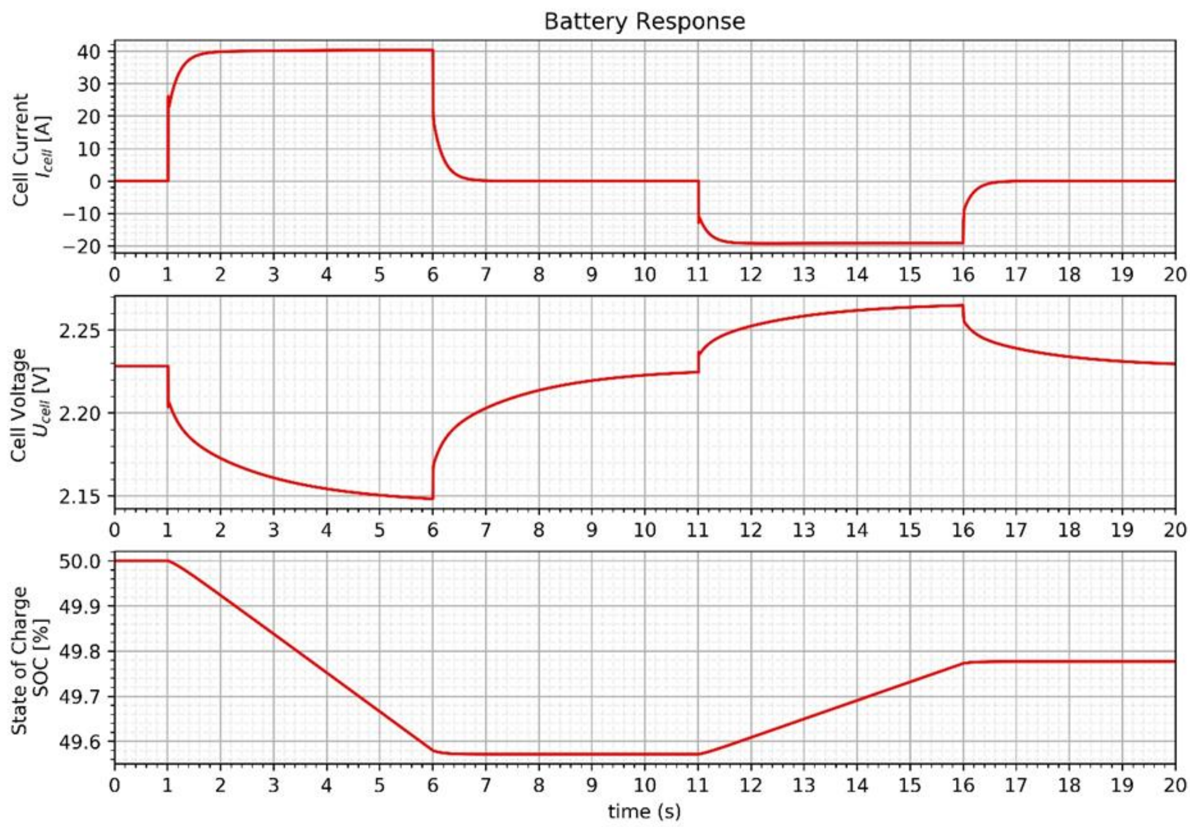

Figure 15 - The Battery Response During Charging and Discharging Intervals

Planned Power Hardware-In-the-Loop Testing

The validation of power-converter-based energy storage devices to be deployed in the power system is challenging, particularly because the advanced functionalities of these power converters are difficult to accurately model. Therefore, it is likely that the system studies carried out using simplified power converter model fail to capture certain dynamics and fault events. In this regard, real-time power hardware in loop (PHIL) test has gained increasing interest in the recent time. The PHIL type of testing provides a high-fidelity validation for any new device or control strategies for power converters connected to the grid. For instance, some of the previous hardware-in-loop test carried out at DTU for evaluating the relay performance under unbalanced fault has resulted in identifying potential malfunction of a real relay under certain converter control strategies. Such an assessment would have been extremely difficult to carry out analytically or just by using numerical simulation. For the Phoenix project, the planned PHIL platform at DTU can cater to high fidelity validation of control system developed for the hybrid synchronous condenser system.

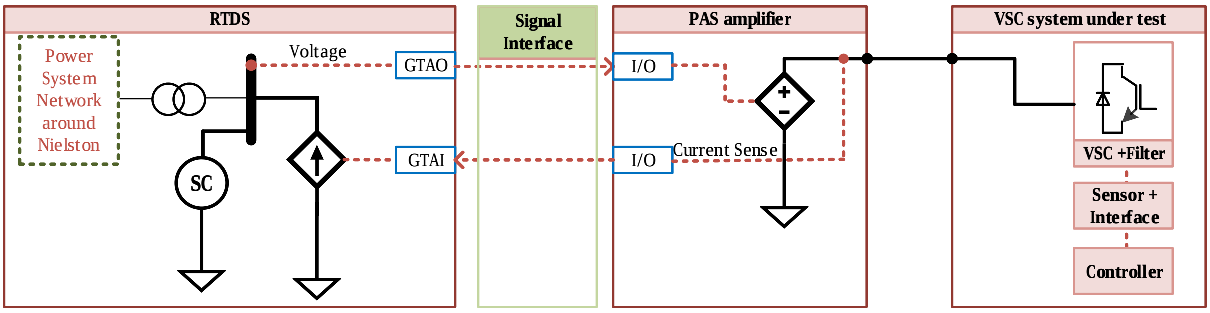

Figure 16 - Overall PHIL system structure

The proposed PHIL setup at DTU is as shown in Figure 16. The proposed system structure has four main components, the real-time digital simulator (RTDS), signal interface section, power amplifier and voltage source converter platform connected to a battery emulator.

The synchronous compensator at Neilston, along with a simplified transmission network model around it provided by SPEN will be modelled in RTDS2. The Nielston bus of the power system simulated in RTDS will be powered up by utilizing the analog I/O terminals of RTDS (GTAO/GTAI) connected to the PAS 4-Quadrant linear Power Amplifier. Therefore, the bus is available for connecting a battery emulator using an actual three-phase voltage source converter (VSC). In this way, there is only signal level interaction between the RTDS and the battery energy storage to provide safe and repeatable conditions. Moreover, such testing also allows the validation under faulted and extreme conditions without damaging laboratory equipment while maintaining a safe environment for operating personnel.

The work plan is to first develop the capabilities of PHIL hardware setup, with steady-state active and reactive power set point control implemented on the battery connected VSC, before advanced grid support functions including frequency regulation and dynamic reactive power support are added to the controller. Afterwards, the model of the master control of the SC+BESS will be implemented in RTDS3. The power grid model around Neilston area will be incorporated at the end when the system is operating stably for simulating under different grid settings.

The procurement of the hardware components needed for the PHIL test is completed. Currently as an initial step towards PHIL, a controller hardware loop test system (CHIL) testing, as shown in Figure 17, is being carried out by interfacing the RTDS and the controller hardware. The preliminary CHIL testing involves a generic grid connected voltage source converter system implemented in RTDS and its control system consisting of decoupled current control with Phase Locked Loop as shown in Figure 18 is implemented in the National Instruments controller

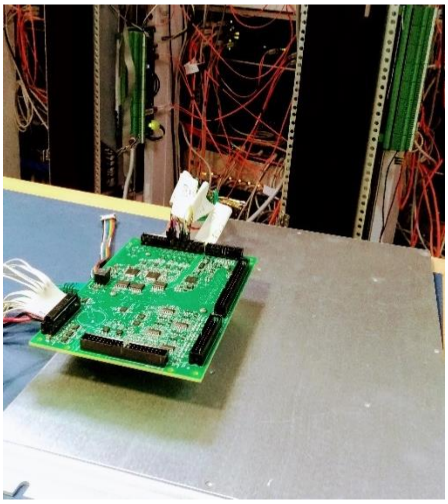

Figure 17 - CHIL test setup with controller hardware and RTDS

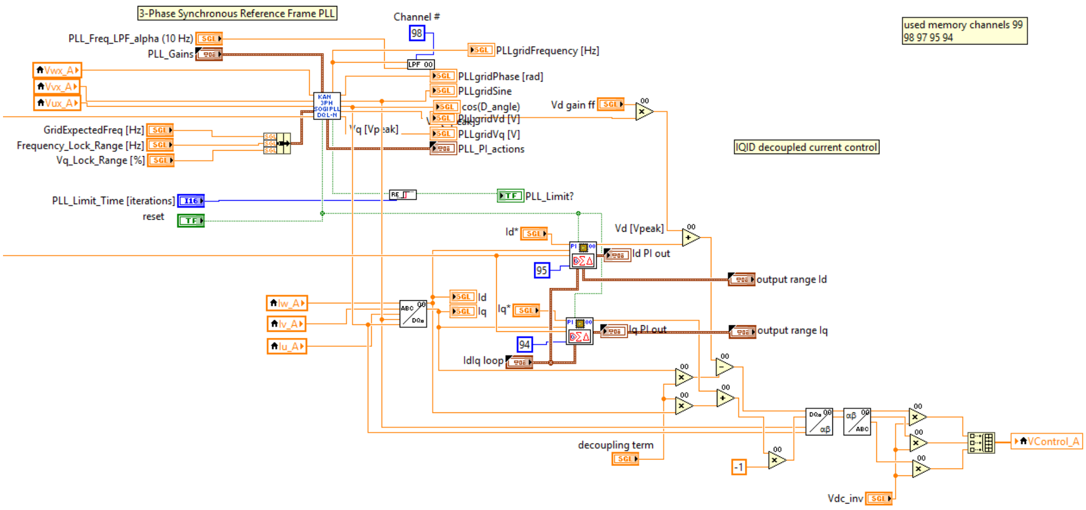

Figure 18 - LabVIEW control system code used for CHIL

Modelling

The following modelling requirements matrix has been jointly developed between all parties to clearly specify each of the project partners modelling requirements and responsibilities to be delivered in Phoenix. The models which have been completed to date are highlighted below with further explanations.

No.	Model	Provider	Use	Platform	Expected Completion Date
1	Synchronous compensator (Neilston)	ABB	Detailed protection studies (DTU)	PSCADX4	Apr-18
2	Synchronous compensator (Generic)	DTU	System studies (NGESO & UoS)	PowerFactory 15.2.5	Jun-18
3	Statcom (Generic)	ABB	System studies (NGESO & UoS)	PowerFactory 15.2.5	Mar-18
4	Type 2 variant for phasor studies (Neilston)	ABB	SSTI and System studies (UoS)	PowerFactory 15.2.5	Mar-19
5	Type 2 variant for EMT studies (Neilston)	ABB	Control development (ABB), System studies (ABB), Protection studies	PSCADX4	Jan-19
6	Type 2 variant for phasor studies (generic/scalable)	ABB	System studies (UoS)	PowerFactory 15.2.5	Sep-19
7	Battery Energy Storage	DTU	System studies (UoS)	PowerFactory 15.2.5	Dec - 18
8	Type 4 variant for EMT studies	DTU	Control studies (DTU)	PSCADX4	Jun-19
9	Type 4 variant for phasor studies	DTU	Control studies (DTU), System studies (UoS)	PowerFactory 15.2.5	Jun-19
10	Reduced GB System Model	NGESO	System studies (UoS)	PowerFactory 15.2.5	Jul-18
11	GB Dynamic system model (full model) - future state(s)	NGESO	System studies (SPEN/UoS)	PowerFactory 15.2.5	Jul-18
12	Reduced Neilston Area System Model	SPEN	Dynamic performance studies in PSCAD (ABB), RTDS studies (ABB)	PowerFactory 15.2.5	Jul-18
13	Reduced Neilston Area System Model	SPEN	System studies (DTU)	PowerFactory 15.2.5	Jul-18
14	EFCC reduced model for studies with EFCC models	UoS	System studies (UoS)	PowerFactory 15.2.5	Nov-18

ABB has delivered the Synchronous Condenser (Neilston) model created in PSCAD. This was delivered to DTU in May to start the Component Studies, where it was used to validate their own PowerFactory Model. ABB also delivered the generic STATCOM model which was created in PowerFactory. NGESO carried out validation of the generic STATCOM model and through several feedback meetings; the model was updated by ABB before being sent to all project partners. The validation of updated STATCOM generic model showed that model is capable to provide the performance as specified in the STATCOM specifications.

ABB confirmed to SPEN that Type 2 variant for Phasor studies (Neilston) model is not required anymore. ABB formally presented to SPEN that the Unit Interaction Factor (UIF) values are considerably smaller than 0.1, whether in normal network scenario or the created radial arrangement. Therefore it was concluded, and subsequently reviewed and agreed by SPEN that as the SSTI risk is very low from the calculations provided, these studies will be omitted from the Phoenix scope and this model will be no longer required.

DTU have delivered the Synchronous Condenser (generic) model in PowerFactory. NGESO also carried out a validation of Synchronous Compensator (SC) generic model and through several feedback meetings; the model was updated by DTU. The validation of updated SC model shows that generic model is capable to provide the performance as specified in the SC technical specifications.
DTU have also provided the Battery Energy Storage System (BESS) model which was created in PowerFactory. This will be used within their studies on an H-SC with Battery Storage available.

SPEN prepared models of the transmission network around Neilston to support the analysis and design work being undertaken by the other project partners. The models, in the PowerFactory software, were extracted from the full GB transmission system model and focus on the area around Neilston where the Phoenix equipment will have greatest influence and interaction with the network. As is normal practice for models of this type, the rest of the GB transmission system was represented by equivalent sources and impedances. The model was modified by replacing actual customer data with generic values to respect confidentiality. Through collaboration with project partners, a range of future network scenarios were assessed to provide models covering normal and extreme conditions.

NGESO has developed dynamic model to represent the full GB system that is suitable to carry out thermal, steady state voltage, fault level analysis and dynamic / Root Mean Square (RMS) simulation for voltage stability and angular stability. The developed GB dynamic model has been reviewed with SPEN and further updates have been carried out based on the feedback received. The GB dynamic model has also been updated to include the generic STATCOM and SC models. The STATCOM and SC generic models were validated to ensure their suitability for integration within the GB dynamic model.

The UoS team has been working closely with the National Grid team to configure the 36-bus reduced GB model to represent a range of different future energy scenarios and operating conditions. The SC and STATCOM models developed by DTU have also been received, tested and integrated to the 36-bus network model.

UoS also have been working on the modelling of a simplified representation of the EFCC scheme in the PowerFactory model for frequency studies. There are two different approaches of representing EFCC in PowerFactory have been investigated:

- Controlling converters (modelled using static generator blocks in PowerFactory) to emulate different response characteristics (e.g. response delay, response power, ramping rate, etc.) to emulate EFCC response.
- Using the EFCC representation in PowerFactory as developed in the EFCC project.

The modelling of the first approach has been completed with a range of simulations have been conducted to demonstrate how the model can be used to represent EFCC response from resources with different capabilities.

The second approach has been investigated as part of the EFCC project. However, formal agreement from National Grid will be required for use the model in the Phoenix project.

The most suitable approach for representing EFCC will largely depend on the system studies to be conducted. The first approach is considered to be more suitable for the quantification of the required H-SC capacity and EFCC response, while the second approach is more suitable for locational studies. The discussion of the actual model used for the studies will be conducted with SPEN and NG.

Knowledge Dissemination & Stakeholder Engagement

Formal Project Kick-Off Event

After suffering contractual delays in 2017, it was decided to host a formal project Kick-Off Event as the project had not started as of yet and there were some key changes to the project partner's teams. We held this event in the IET Teacher Building in Glasgow on the 22nd February. This was well attended by all partners and some stakeholders. We started the day with SPEN presenting an overview of the project and the reasons for the project, before launching into an ice-breaker introduction exercise to get to know one another better.

After a short break, all of the project partners gave presentations stating who they are, what their involvement is with Phoenix and what they see as the key challenges going forward. This was very well attended by the partners and gave a real insight into the interesting challenges of Phoenix. The day was then finished with a Q&A session where some of our stakeholders were able to ask questions on the delivery plan and key outcomes of the project.

Stakeholder Engagement Event

In order to fully understand who our stakeholders were for Phoenix, we went through an exercise in line with the General Data Protection Regulation (GDPR) 2018 and the Data Protection Act (DPA) 2018 by emailing a list of around 250 names that had previously highlighted an interest in innovation, transmission and synchronous generation projects. We now have a list of 56 names (and growing) that have registered a firm interest in Phoenix and will receive updates and invitations to various events throughout the project.

On 24th May 2018, we held a successful Stakeholder Engagement Event at the Hilton Grosvenor Hotel in Glasgow's West End. The event started with SPEN giving a general overview of the project and the reasons behind Phoenix, the choice of Neilston Substation and the benefits in which the H-SC will deliver. We then gave a general project update to the stakeholders before each of the project partners presented on both their role within the project and on progress to date. After lunch our stakeholders had the chance of two different breakout sessions dependant on their interests – Commercial Breakout Session chaired by NGESO and The Market Specialist or a Technical Breakout Session chaired by ABB. From this event we have managed to assess the interests of the stakeholders with the view to plan further Technical and Commercial events at key times within the project.


Figure 19 – Stakeholder Engagement Event, 24th May Glasgow

Figure 20 – Stakeholder Engagement Event, 24th May Glasgow

Commercial Working Group – September 2018

From the Stakeholder Event in May we issued a further opportunity to become a member of the Commercial Working Group for Phoenix. From this we have confirmed the memberships taking into account the requirement to have members from Equipment Suppliers, Generators, Product Developers, Networks, Aggregators, Policy Makers and Trade Groups. From this we have a group of 14 members from a variety of backgrounds all with a strong commercial interest in Phoenix.

The purpose of the Working Group is to provide a forum for interested stakeholders and industry experts to help shape the regulatory and commercial arrangements for H-SCs. The Commercial Working Group members will do this by informing the commercial work activities undertaken for Project Phoenix and by providing their expertise and perspectives from their industry areas. The Working Group will support the fundamental principles of developing market solutions in a coordinated and transparent manner, whilst creating a level playing field for all parties. The group is chaired by the independent Market Specialist where they will meet up every 3-4 months.

On 11th September the Commercial Working Group met for the first time at the IET Savoy Place Building in London. After an introduction to the Phoenix project and an update on progress and National Grid's operability challenges, the Commercial Working Group reviewed the overall commercial work plan, the CBA methodology and the approach to the international assessment.

The next meeting is scheduled for March 2019. After this, the group will meet every 3 to 4 months. A draft programme of works for the Commercial Working Group has been issued and this will be updated through the project to ensure that key commercial aspects are addressed.

Look Ahead to the Next Reporting Period

Looking ahead to the next reporting period, the following key activities are expected:

Research, Modelling and Studies

- During the next reporting period, NGESO plan to carry out system studies to determine the benefit of a 140 MVA H-SC at Neilston 275kV, compared with other options such as SC, STATCOM and SC and STATCOM without hybrid control and to carry out CBA to evaluate the benefit of H-SC
- NGESO also plan to carry out further system studies to determine the benefit of H-SC for different rating and locations
- DTU will be focusing on the modelling of the BESS + SC hybrid system, both in PowerFactory (phasor studies) and in PSCAD (EMT studies)
- DTU will also be designing and modelling of coordinated control for the BESS + SC system (type 4 variant), before completing a preliminary PHIL study report on impact of BESS + SC on Nielston area power system. This will be incorporated with the Reduced Neilston Area System Model which SPEN have delivered
- UoS will be conducting a wider range of studies (e.g. frequency disturbances, faults at wider geographical locations, etc.) using the SC and STATCOM models developed by DTU
- ABB will be delivering the Type 2 variant for EMT studies (Neilston) model as well as the Type 2 variant for phasor studies (generic/scalable); currently information is in the process of being gathered with the modelling aspects starting early 2019

Design and Construction

- ABB are planning to start the site and Civil works in January, 2019, and the works will proceed in Q1 and Q2, with preparing e.g. the foundations for the main components and construction of the STATCOM building.
- The Installation works of the main components for the system will then start in end of Q2 and will continue until end of Q3. Commissioning of the Phoenix H-SC will then be made in Q4 where the H-SC will be energised before the end of 2019 starting the 12 month Live Trial.
- ABB are currently working on the control system, where this will be set-up and the software implemented in the ABB test area in Sweden during Q1 before final Factory Acceptance Test planned for end of March.
- This is in line with the current FAT Schedule of all components which will be running through February and March.
- SPEN Projects will begin site and Civil works for the 275kV Bay, in which Phoenix will connect to, in April 2019 before meeting the outage date for connection which has been booked for July 2019.

Commercial

In the first half of 2019, the main focus of the commercial work for both the Market Specialist and NGESO will be the continuing assessment of value at Neilston and the international assessment:

- System Studies for Neilston – work will continue to assess the value of the H-SC and other options at Neilston. This should be completed by August 2019.

- International Assessment – further interviews and case studies will be carried out to complete a report by June 2019.
- Impacts on Existing Schemes and Markets – an initial assessment of impact areas will be carried out and reviewed with the Commercial Working Group. This will help shape the subsequent work in this area.

In the second half of 2019, the Commercial Work Package will focus on the following:

- With the installation of the H-SC at Neilston in late 2019, work will begin to validate the value assessment for Neilston including the power system analysis and cost benefit models for the H-SC. Early work will include the identification of any specific Neilston test requirements.
- Potential opportunities for the use of H-SCs and similar assets on the wider GB network will begin to be identified.
- If benefits are apparent, work will begin to consider the ownership and commercial options for H-SCs and similar equipment.

Knowledge Dissemination

In terms of knowledge dissemination activities, Phoenix will engage with the key internal stakeholders through the following activities during the forthcoming period:

1. Technical Stakeholder Engagement Event – there has been increased interest from our Stakeholders, both internal and external, about a Technical Event. SPEN and ABB are planning to host an event mid-late January where the H-SC Design will be discussed, alongside any learning outcomes so far. ABB will then present on the innovative Master Control System and the progress on this to date. SPEN and ABB are currently finalising the agenda for this event, alongside booking a suitable venue.

2. Neilston Knowledge Dissemination Room – We are currently developing our plans for the CDM Welfare area on site with the intention of hosting small groups for the purposes of Knowledge Dissemination from March 2019. On a regular basis we aim to host groups in the meeting room which will over-look the Phoenix Construction works.

3. Videography Works – We plan to film a majority of the Site Works throughout 2019. This will coincide with the Site programme and key activities/milestones. We will work closely with the Scottish Power studio to edit all filming to create a Knowledge Dissemination Video by the end of 2019.

4. Phoenix Commercial Working Group – There are two Commercial Working Group meetings planned for the next reporting period. The next meeting will be held in London, similarly to the first meeting which happening during this reporting period. Later in the year we are planning to host the Commercial Working Group on site if availability allows.

5. Stakeholder Engagement Event – Depending on the programme, there is potential to hold another Stakeholder Event in the last quarter of the next reporting period. This will be after the construction and commissioning works leading up the date where the H-SC will be energised which is planned for the end of 2019. We will assess this closer to the time, and discuss with all project partners.

Consistency with Full Submission

At this early stage of the project deliver, Phoenix remains consistent with the original Full Project Submission with regards to budget, however as previously mentioned the project programme and milestone dates have been adjusted and agreed with all partners to combat the contractual delays we suffered in 2017. Additionally we have taken on extra resources which were not previously considered, as a proactive measure to keep to the planned end date of the project.

Successful Delivery Reward Criteria

The Successful Delivery Reward Criteria (SDRC) set out in the Project Direction links with the Project Milestones and the identified targets directly. This SDRC can be used to check the progress of the project delivery and position the progress against the original proposal. A full list of the SDRC is provided in Appendix 2 for reference.

The table below lists all the required SDRCs which were delivered within reporting period of 2018:

Successful Delivery Reward criterion	Evidence
1) Architecture, Design and Engineering feasibility Engineering design and feasibility analysis for pilot H-SC deployment and demonstration. Site selection and planning consent for H-SC installation. Detailed layout, civil designs and approval through system review group for finalising tender for site works and ordering equipment.	1. Report on engineering and design feasibility analysis. WP1 2. Report on environmental studies and life cycle analysis. WP1 3. Report on detailed installation diagrams and site layouts. WP1 4. Report on routine and type testing procedure and results. WP1
2) Financial Value Evaluation and Regulatory Recommendations Develop and demonstrate a commercial framework to financially incentivise services provided by synchronous condenser. Enable service providers to participate in a new market for inertia and other ancillary services provided by SCs. Create recommendations for regulatory considerations for future roll-out of SCs/H-SCs.	1. Cost benefit analysis model for SCs and H-SCs. WP3
3) Control Methods Development and Testing Innovative control methods to maximize benefits of SC/H-SC installations in different network conditions and different locations across GB. Simulation of co-ordinated control schemes with other network components such as SVCs, STATCOMS and battery storage. Development and on-site testing of hybrid control scheme for H-SC.	1. Report on methods and functional specifications of hybrid
4) Lab Functionality and Component Model Testing Testing of different operational scenarios in laboratory environment to generate results to better understand performance of SC/H-SCs under various limits and constraint conditions. Lab testing will test different operational parameters of SC/H-SCs. Use of RTDS to facilitate simulation of technical models and control algorithms.	1. Component model adapted to pilot demonstration and for further system studies. WP5 2. Report on component level studies from SCAPP project and relevance to pilot demonstration and future installations. WP5 3. Report on co-simulation for faster prototyping for new designs and controls. WP5
5) Application of synchronous condenser: GB system studies System studies using SC/H-SC component model and GB system model developed through EFCC project and SOF studies to critically analyse impact of future roll-out of SC/H-SCs in GB network. Case studies for specific system cases on	1. Report on System Studies and Quantification of overall benefits from application of SCs/H-SCs in GB system. WP5

GB network.	
7) Performance Monitoring Monitoring of equipment performance such as losses, vibrations and maintenance requirements of rotating parts of the pilot H-SC. Condition monitoring of the H-SC output and impact on the regional and wider power system.	3. Functional specifications for H-SC output monitoring - Methods and User Interface. WP2
8) Knowledge Dissemination Stakeholder engagement and dissemination of learnings and outcomes of the pilot H-SC demonstration through project.	3. Innovation Testing and Demonstration Workshop. WP6 4. Project Phoenix regular project progress reports. WP6.

The following SDRC are due for completion in the forthcoming period:

Successful Delivery Reward criterion	Evidence
2) Financial Value Evaluation and Regulatory Recommendations Develop and demonstrate a commercial framework to financially incentivise services provided by synchronous condenser. Enable service providers to participate in a new market for inertia and other ancillary services provided by SCs. Create recommendations for regulatory considerations for future roll-out of SCs/H-SCs.	2. Report on cost benefit analysis of SCs and H-SCs based on system studies and FES. WP3 3. Report on international application of SCs and benefit analysis. WP3 4. Report on value evaluation of SCs/H-SCs based on pilot installation and performance. WP3
3) Control Methods Development and Testing Innovative control methods to maximize benefits of SC/H-SC installations in different network conditions and different locations across GB. Simulation of co-ordinated control schemes with other network components such as SVCs, STATCOMS and battery storage. Development and on-site testing of hybrid control scheme for H-SC.	4. Report on methods and functional specifications of innovative control schemes for future roll-out. WP4 5. Report on FAT test procedure and results of pilot hybrid co-ordinated control system. WP4
5) Application of synchronous condenser: GB system studies System studies using SC/H-SC component model and GB system model developed through EFCC project and SOF studies to critically analyse impact of future roll-out of SC/H-SCs in GB network. Case studies for specific system cases on GB network	2. Report on case studies on system characteristics of SCs/H-SCs in conjunction with other innovative solutions proposed through EFCC and HVDC converters. WP5 3. Report on optimal placement and capacity evaluation of SCs/H-SCs in GB. WP5
6) Pilot Installation and Operational Trial On-site installation and commissioning of pilot H-SC demonstration. Civil work and	3. Report on SAT procedure and test results. WP1 5. Report on extended live trial and recommendations for future installations

electrical connection of H-SC to the transmission network.	
7) Performance Monitoring Monitoring of equipment performance such as losses, vibrations and maintenance requirements of rotating parts of the pilot H-SC. Condition monitoring of the H-SC output and impact on the regional and wider power system.	4. Functional specification for H-SC wider system operational performance monitoring WP2
8) Knowledge Dissemination Stakeholder engagement and dissemination of learnings and outcomes of the pilot H-SC demonstration through project.	3. Innovation Testing and Demonstration Workshop. WP6 4. Project Phoenix regular project progress reports. WP6.

Learning Outcomes

During the reporting period the H-SC Preliminary Design has been on-going alongside pre-construction CDM planning. There have been no substantial learning outcomes to date however, with the detailed design and model development almost complete and site mobilisation scheduled for late January we anticipate key learning related to final design and operation during the forthcoming period.

Business Case Update

[redacted]

Bank Account [Confidential]

[redacted]

Intellectual Property Rights [Confidential]

[redacted]

Other

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Accuracy Assurance Statement

I therefore confirm that processes in place and steps taken to prepare the PPR are sufficiently robust and that the information provided is accurate and complete.

Signature:

Name (Print): Craig Hume

Title: Project Manager

Date: 06/02/2019

Signature:

Name (Print): James Yu

Title: Future Networks Manager

Date: 31/01/2019

Appendices

Appendix 1 – Phoenix Successful Delivery Reward Criteria

Successful Delivery Reward criterion	Evidence
1) Architecture, Design and Engineering feasibility Engineering design and feasibility analysis for pilot H-SC deployment and demonstration. Site selection and planning consent for H-SC installation. Detailed layout, civil designs and approval through system review group for finalising tender for site works and ordering equipment.	1. Report on engineering and design feasibility analysis. WP1 2. Report on environmental studies and life cycle analysis. WP1 3. Report on detailed installation diagrams and site layouts. WP1 4. Report on routine and type testing procedure and results. WP1
2) Financial Value Evaluation and Regulatory Recommendations Develop and demonstrate a commercial framework to financially incentivise services provided by synchronous condenser. Enable service providers to participate in a new market for inertia and other ancillary services provided by SCs. Create recommendations for regulatory considerations for future roll-out of SCs/H-SCs.	1. Cost benefit analysis model for SCs and H-SCs. WP3 2. Report on cost benefit analysis of SCs and H-SCs based on system studies and FES. WP3 3. Report on international application of SCs and benefit analysis. WP3 4. Report on value evaluation of SCs/H-SCs based on pilot installation and performance. WP3 5. Report on impact of SCs/H-SCs on existing balancing schemes and markets. WP3 6. Report on value analysis from roll out of SCs/H-SCs in GB in future potential sites. WP3 7. Report on regulatory considerations and recommendations for future roll-out of SCs and H-SCs. WP3
3) Control Methods Development and Testing Innovative control methods to maximize benefits of SC/H-SC installations in different network conditions and different locations across GB. Simulation of co-ordinated control schemes with other network components such as SVCs, STATCOMS and battery storage. Development and on-site testing of hybrid control scheme for H-SC.	1. Report on methods and functional specifications of hybrid control mechanisms developed and trialled in pilot demonstration. WP4 2. Report on output of SCAPP project on protection and control of synchronous condenser and simulation results of new control methods. WP4 3. Report on performance of pilot hybrid co-ordinated control system. WP4 4. Report on methods and functional specifications of innovative control schemes for future roll-out. WP4 5. Report on FAT test procedure and results of pilot hybrid co-ordinated control system. WP4 6. Report on SAT test procedure and results of pilot hybrid co-ordinated control system. WP4
4) Lab Functionality and Component Model Testing Testing of different operational scenarios in laboratory environment to generate results to better understand performance of SC/H-SCs under various limits and constraint conditions. Lab testing will test different operational parameters of SC/H-SCs. Use of RTDS to facilitate simulation of technical models and control algorithms.	1. Component model adapted to pilot demonstration and for further system studies. WP5 2. Report on component level studies from SCAPP project and relevance to pilot demonstration and future installations. WP5 3. Report on co-simulation for faster prototyping for new designs and controls. WP5
5) Application of synchronous condenser: GB system studies System studies using SC/H-SC component model and GB system model developed through EFCC project and SOF studies to critically analyse impact of future roll-out of SC/H-SCs in GB network. Case studies for specific system cases on GB network.	1. Report on System Studies and Quantification of overall benefits from application of SCs/H-SCs in GB system. WP5 2. Report on case studies on system characteristics of SCs/H-SCs in conjunction with other innovative solutions proposed through EFCC and HVDC converters. WP5 3. Report on optimal placement and capacity evaluation of SCs/H-SCs in GB. WP5 4. GB roadmap for roll-out of SCs/H-SCs. WP5
6) Pilot Installation and Operational	1. Report on site installation process, details and

Trial On-site installation and commissioning of pilot H-SC demonstration. Civil work and electrical connection of H-SC to the transmission network.	recommendations for future - Civil. WP1 2. Report on site installation process, details and recommendations for future - Electrical. WP1 3. Report on SAT procedure and test results. WP1 4. Report on electrical layout of H-SC design with protection and control architecture. WP1 5. Report on extended live trial and recommendations for future installations
7) Performance Monitoring Monitoring of equipment performance such as losses, vibrations and maintenance requirements of rotating parts of the pilot H-SC. Condition monitoring of the H-SC output and impact on the regional and wider power system.	1. Report on pilot H-SC installation component level SC, STATCOM condition monitoring. WP2 2. Process documentation for SC type testing requirements for future installations. WP2 3. Functional specifications for H-SC output monitoring - Methods and User Interface. WP2 4. Functional specification for H-SC wider system operational performance monitoring WP2 5. Report on pilot H-SC installation output data logging and monitoring WP2 6. Report on H-SC system impact in local and wider system context - Usage, Control methods and Interactions. WP2
8) Knowledge Dissemination Stakeholder engagement and dissemination of learnings and outcomes of the pilot H-SC demonstration through project.	1. Report summarising findings of TO SO working groups. WP6 2. Report on emerging technical standards for synchronous condenser. WP6 3. Innovation testing and Demonstration Workshop WP6 4. Project Phoenix regular project progress reports. WP6. 5. Project Phoenix Close down report. WP6

Appendix 2 – Project Risk Register [Confidential]

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www.spenergynetworks.co.uk/
facebook.com/SPEnergyNetworks/
twitter.com/SPEnergyNetwork
phoenix@spenergynetworks.co.uk