Phoenix - System Security and Synchronous Condenser

In collaboration with

Project Progress Report

[Internal]

December 2017

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1 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 March 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 condenser (STATCOM) flexible AC transmission system (FACTS) device, referred to in the project as a Hybrid Synchronous Condenser (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. This will enable future installations and essential network services to be provided for GB Transmission Owners and Operator, including Distribution and Offshore network operators.

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

1.1 Project Highlights

This is the second in the series of biannual progress reports for the Phoenix project, covering the project delivery period June 2017 – December 2017, “the reporting period”. The most significant developments during the period are listed below:

- Contracts signing nearing completion with all Project Partners, detailing project deliverables, deadlines and payment schedules:
  - National Grid, contract terms in final stages of legal negotiations, signature expected late December 2017 / early January 2018
  - University of Strathclyde, contract terms agreed, contract signed
  - Technical University of Denmark, contract terms agreed, contract signed
  - ABB, contract terms agreed, contract signed.
- Due to contractual delays, milestones and payments were successfully re-negotiated with all partners agreeing to the new deliverable dates
- After a tendering process, we are in the final negotiations with an experienced Market Specialist who will formally begin work in January 2018
- Successful introduction meetings have been held with all partners, as team members have changed from the original agreed project teams at the start of 2017

- Kick-off meetings and workshops planned for late January / early February 2018

1.2 Project Risks

We are currently running at a delay of about six months. This has been due to significant contractual delays which involved legal and procurement. These delays unfortunately present a new risk that could impede on the delivery of the SDRC's, therefore it was agreed with all partners that we would push the first few project's SDRC deliverables back by around six months, however we do still plan to finish on the agreed date of March 2021. We monitor risks on a continuous basis with regular review at monthly progress meetings. The key risks are summarised below, with more details in Section 4.

1.2.1 Technical Risks

The following technical risks have been identified:

- Outage Window overrun. On-site implementation of a large scale transmission infrastructure project. Phoenix on-site work time extends beyond the outage window.
- Limited specialist commercial expertise. Limited specialist market expertise within SPEN to support development. Effective commercial mechanisms required to enable deployment of technology.
- Lack of operational experience. Unproven hybrid technologies with no live network experience of the control interactions between a SC and a STATCOM
- Lack of installation experience. New technology will require new training and procedures to be followed which introduces risk of overrun during installation.

1.2.2 Project Management Risks

The follow project management risks that have been encountered during the reporting period are listed below. Project Managers at each of the project partners have ensured that these risks are continuously monitored and actively managed to ensure the project milestones are not jeopardised:

- Contractual Delays. This has caused the SPEN to make the decision to push the first few SDRC's back, and progress from all partners will be monitored on a monthly basis to ensure we still deliver the project on time.

Further details of Risk Management including Technical Risk and Project Management Risk can be found in Section 4 of this document.

1.2.3 Summary of Learning Outcomes

At this early stage of the project, there are no major learning outcomes of note.

2 Project Manager's Report

This section highlights the projects' key activities, milestones, risks and learning over the second reporting period (June2017 – December 2017).

2.1 Project Progress Summary

In the first months of the project, the significant achievements during the period are:

- Contractual meetings held independently between SPEN and each Project Partner to finalise detailed deliverables and project plans to combat the delays through a change management process.
- Contracts signing nearing completion with all Project Partners, detailing project deliverables, deadlines and payment schedules:
    - National Grid contract is the only contract outstanding, contract terms in final stages of legal negotiations, signature expected late December 2017 / early January 2018
- In the final negotiations over recruiting an Independent Market Specialist after a successful tendering process
- Hosted a well-attended Stakeholder Engagement Event held at The Technology & Innovation Centre, Glasgow in July 2017

In the coming months, there are plans for:

- Formal Kick-off meeting with all project partners
- Design Workshop between ABB and Principal Contractor (SPEN Projects)

2.2 Project kick-off and administration

During this current part of the project, the main focus has been on agreeing contractual terms between all parties ahead of the official kick-off meeting (last contract expected to be signed before year end).

During the fourth quarter of the year, technical meetings have been held in order to significantly progress the important aspects of design and modelling responsibilities and requirements from each party in determining deliverable specifics and dates.

With regards to project resourcing, the following progress has been made:

- The structure of the Project Team has been agreed between all Project Partners.
- Key internal stakeholders within SP Energy Networks have had continuous involvement with the project by providing input into technical design requirements.

- In SP Energy Networks, Phoenix has currently 1FTE equivalent representation from Engineering Design and Standards, Network Planning and Regulation and Transmission Operations team.
- We are in the final negotiations with an Independent Market Specialist will formally begin work January 2018. The market specialist will be working to develop a cost benefit analysis model to assess the potential commercial opportunities available for the technology behind Phoenix in today's electricity markets and frameworks.

2.3 Project Plan

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

Workpackage 1: Hybrid Synchronous Condenser Installation

- 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.

2.4 Team Structure

The team structure of the project is depicted in the figure below.

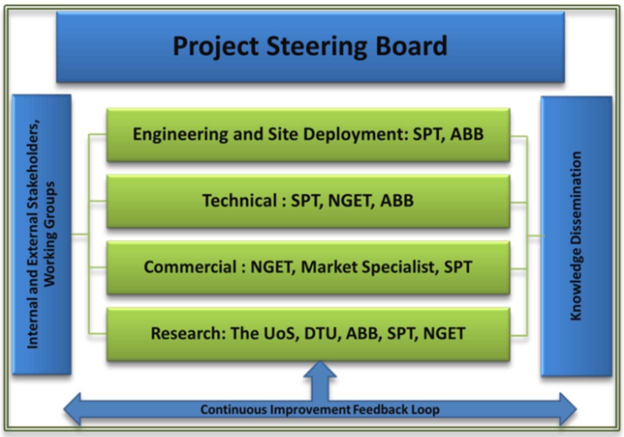


Figure 1. Team structure for project Phoenix

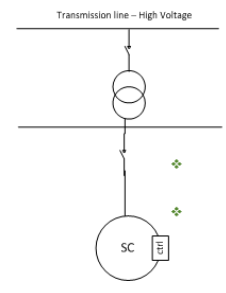
2.5 The Phoenix Solution

2.5.1 Overview

A high-level outline of the Phoenix solution was identified as part of the project design and scoping stage submitted to Ofgem in the project proposal in 2016. In order to ensure the most efficient and cost effective recommendations for the future use of Synchronous Condenser in GB, four design "variants" will be investigated by this project; variant 2 by deployment and variants 1,3, and 4, through modelling and case studies:

- Variant 1: Standalone SC
- **Variant 2: Hybrid SC (Phoenix solution to be installed)**
- Variant 3: Hybrid SC + self-start + Black Start
- Variant 4: Hybrid SC + Battery Energy Storage System

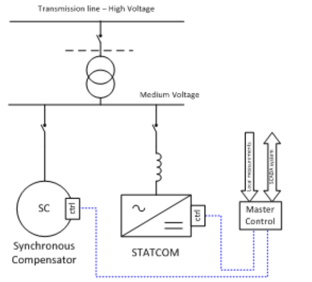
1. Standalone



- Retrofitted Synchronous Generation Plant
- New Synchronous Compensator

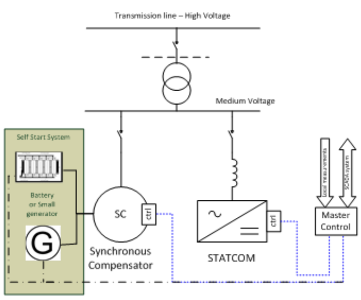
- Enable commercial mechanisms to enable procurement of services from service providers
- Prove engineering feasibility and performance

2. H-SC SC + STATCOM



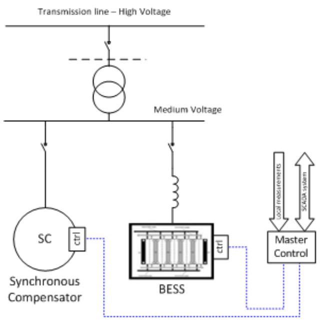
- Design, develop, simulate and deploy on live system hybrid-coordinated control mechanisms
- Maximise strengths of both technologies minimise weaknesses

3. H-SC SC + STATCOM + Self Start up - Blackstart



- Simple extension from variant 2 with self start mechanism

4. H-SC SC + Battery Energy Storage System (BESS)



- Simple extension from variant 2 moving from DC-capacitors in pure STATCOM to battery energy storage system.
- The component models for this variant will developed and simulated in Phoenix research studies

Figure 2. Synchronous Condenser design variants

By considering multiple variants of SC designs Phoenix aims to cover the necessary technical and commercial challenges for each design so that the findings and final recommendations are both robust and viable. In addition, detailed system studies and financial value analysis across all potential system support services will be performed to estimate the number and type of SC/H-SC units to provide necessary level of support to the GB system; all of which work toward the project achieving a fundamental objective - to inform future investment decision making regarding roll-out.

2.5.2 Hybrid Synchronous Condenser Technical Details

The hybrid synchronous condenser solution to be installed as a 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;
- Enhance the oscillation damping capability;
- 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 latest version of the single line diagram of the draft H-SC is provided below, and a system-level diagram in Appendix 1 (confidential).

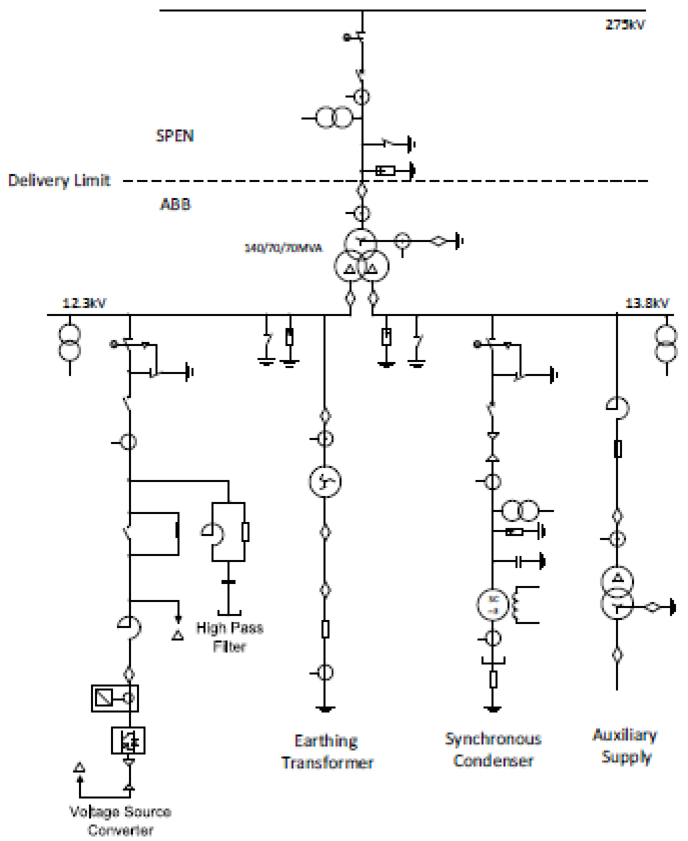


Figure 3. Single line diagram of the H-SC

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 below.

2.5.3 The Synchronous Condenser branch

The SC branch comprises of the condenser connected via a cable to the branch power switch along with measurement devices and protection components. The SC will be a three phase, synchronous, four pole 50 Hz type with a synchronous speed of 1500 RPM and shall be designed to;

- 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

2.5.4 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.

2.5.5 The hybrid co-ordinated control system - MACH

The fully redundant 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 and isolated from the system through 13.8 kV disconnectors. In such case, the control system will automatically adapt to the H-SC system configuration.

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 will change the SC normal 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.
- Synchronous condenser reactive power x field current curves are given assuming 1.0 per-unit voltage at machine connecting point. Due to STATCOM operation, this voltage will constantly change, which will cause small deviations on the machine operating point. The effect on the closed loop response will be analysed although the use of separate transformer windings for connecting the STATCOM and SC branches partly mitigates this interaction.
- Since each equipment has its own controller, ABB will put lots of 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. For signals requiring faster communication, hardwiring will be used.

2.5.6 Chosen installation site

The site to installed the H-SC has been chosen to be Neilston 275kV substation

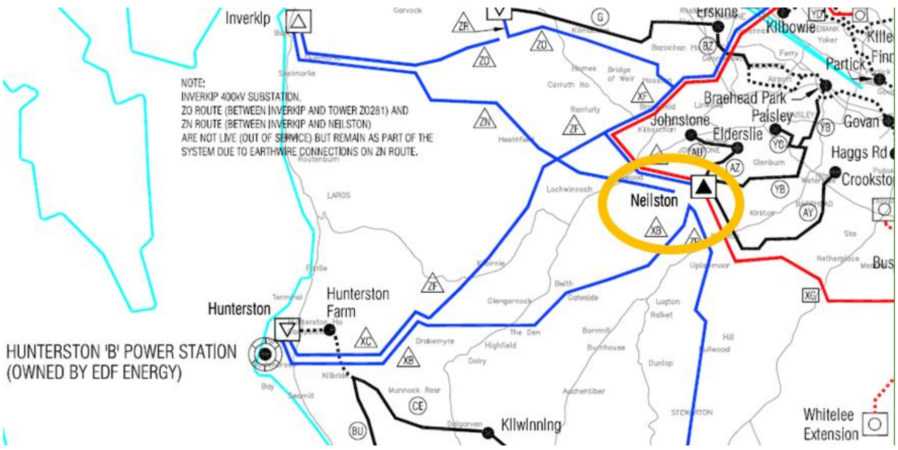


Figure 4. Installation site: Neilston 275kV Substation

2.6 Research Updates

Technical University of Denmark have made significant starts on research for Phoenix, by writing on first the concept and challenges of inertia and short circuit power, and the modelling practice in DTU.

2.6.1 Inertia of an Electric System

The replacement of synchronous generators by renewable energy sources reduces the electromechanical coupling and hence the inertia of the system. Over the years there have been great discussions regarding the effect of reduced inertia of the system, and the restoration of the inertia of the system through a manner of control acting as a virtual inertia to the system.

What is inertia of an electrical power system? Inertia is an inherent property of a physical object that resists to any external forces. The rotor of the generator is a rigid body, whose rotation provides a source of the inertia to the power system. Considering a system is under an ideal situation of power balance without even smallest disturbances and oscillations, for synchronous machines, the movement of magnetic motive force (MMF) of the stator and rotor are at the same speed with a constant phase displacement, either leading or lagging depending on the mode of operation. When a disturbance occurs in the electrical system, there is a momentary unbalance between the mechanical power and electrical power of the machine, reflected by an instantaneous change of the relative phase displacement between the armature and rotor MMF, due to the inertia of the rotor rotation. The change of phase displacement will instantaneously affect the power output of the machine to regain power balance, acting as the inertia of the electric system. This inertia response is purely physics and passive, and acts instantaneously against any disturbances in the system without the need for control in place. This response, however, cannot sustain for long since the speed of the machine hence the power frequency will change afterwards without changing the energy input. In order to maintain the speed of the machine and the system frequency, frequency control will take effect shortly after a disturbance to diminish the power unbalance in the system.

Synthetic inertia (SI), instead, emulates the inertia effect by taking df/dt as a control object. Discussions on synthetic inertia also include taking df as input but with faster response than normal frequency control. Recent research moves in a direction that tries to match converter control model with the motion model of synchronous machines in order to achieve similar electric characteristics during disturbances. The control of synthetic inertia, though can effectively affect the frequency response, is yet commonly accepted by the community as an alternative of the physical inertia that is natural, passive and spontaneous during disturbances, due to;

- The inception of SI control is that frequency is an indicator of the power balance, which means there are still sufficient amount of synchronous machines in the system that determines the frequency;
- As achieved by control, the response is subject to delay, accuracy and actuation of the measurement and control system and its reliability.

Grid codes are under development in this field regarding the response characteristics of synthetic inertia. Conceptually, one must not mix synthetic inertia with intrinsic inertia, as each represents different effect and ability in low inertia system operations.

2.6.2 Short Circuit Current

Short circuit power is a key parameter that grid planners monitor and maintain to ensure a proper voltage stability and quality against various operation switches and disturbances in the system. It is also important from system security point of view, where sufficient short-circuit current can properly trigger the protective relays to protect the equipment and the system during the faults.

Though the majority of the faults, in reality, is unbalanced faults, the analysis starts from balanced faults as it represents a simpler yet severe case. For alternators, during the normal operation, the magnetic field of the rotor interact with the rotating magnetic field generated from the stator, no matter in generator or motor mode. During balanced faults, the field from the stator will become weaker, due to the decrease of voltage, while the field of the rotor acts as an energy source that induces voltage at the stator winding and provides short circuit current to the system. The currents of at least 2 phases have both DC and AC components. The decay of DC component depends on the R/X ratio of the system, as long as the rotor field and speed keeps the same. If R is zero, the DC component will never decay, while if X is zero, there is no DC component. The machine internal impedance and the grid impedance determine the AC components. For induction machines, the short circuit contribution is shorter due to no supply to the rotor field, while for synchronous machines the contribution is longer. The frequency of the current may differ from the voltage in the system due to the variation of the speed of the rotor.

For unbalanced faults, the currents from generators can contain significant active power components during faults flowing through unfaulted phases, compared to motors. The exact current characteristic depends on the design of the machine and the characteristics of the magnetic circuit. The current composes different sequence components, assuming the current and voltage have the same frequency. Negative sequence component appears in unbalanced faults while zero sequence is from ground faults. Similar to inertia response, the behaviour of alternators in the first few cycles are passive and spontaneous. The behaviour of alternators during faults is the nature of voltage source, and the current magnitude can range approximately from 4 to 8 times of the rated current for the first 3-5 cycles.

Converters are controlled current source where specified control strategies can be developed for faults to support positive or negative sequence active or reactive power in both directions based on specifications. Furthermore, through specific control converters can inject constant active or reactive power, or balanced current. Current frequency and phase should follow the grid voltage frequency and phase that is measured by the phase lock loop. The converter current characteristics can be flexibly set and no DC offset. However, the RMS magnitude has to be within the limit of the IGBT that makes it maximum value around 1.2 pu.

2.6.3 Modelling of DK System in RTDS

The simulation will be eventually based on the Western Danish system (DK1) in 2025 prepared by Danish TSO Energinet.dk. The original system model is modified through simplifications and aggregations, and only the key components are modelled to comply with the nodal limits of the real-time digital simulators (RTDS). For example, the 3 LCC HVDC links to Norway are aggregated into 1 link, while two wind farms at Horns Rev (Horns Rev B, C) based on type 4 wind turbines of VSC type are aggregated into 1 wind farm. The base system model is validated from two real events on both frequency and short circuit. Here, the base case system represents the current DK1 system without the addition of the new facilities as planned.

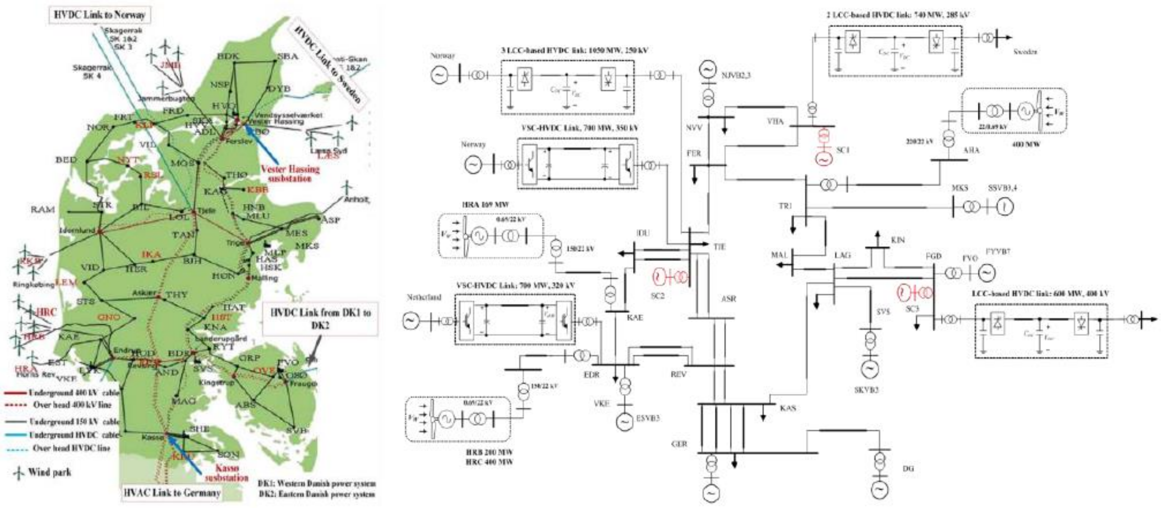


Figure 5. The System to be used by study by DTU

2.6.3.1 Validation results from frequency event

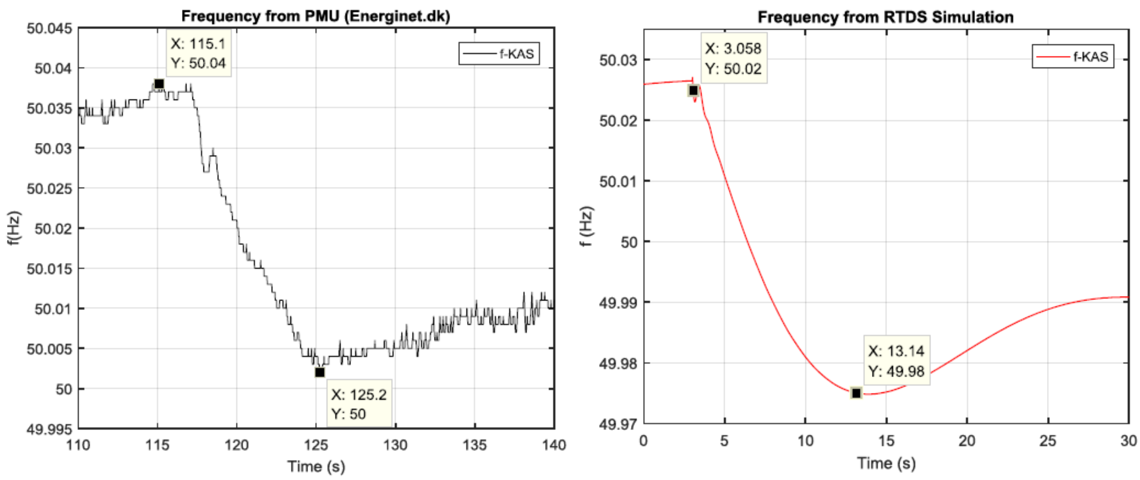


Figure 6. Frequency Validation Plan

From Figure 6, the model in simulation shows similar inertia characteristic given the same disturbance as the event in the real system.

2.6.3.2 Validation results from short circuit event

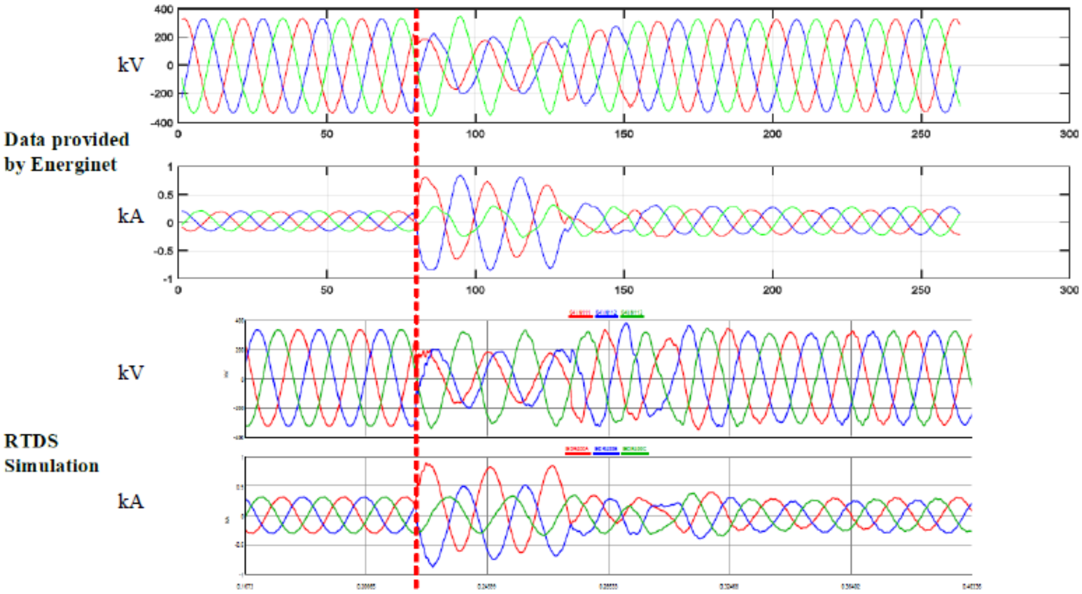


Figure 7. Validation Results for a Short Circuit Event

From Figure 7, simulation obtains a similar result as the measurements. In Phoenix project, we expect to continue the use of DK system for simulation of the effect of condenser systems. This is to ensure the results are rooted from a solid practical background.

2.7 Modelling requirements

The following modelling requirements matrix has been jointly developed between all parties to clearly specify each parties' modelling requirements and responsibilities to be delivered in Phoenix:

No	Model	Provider	Use	Platform	Req. Date
1	Synchronous compensator (Neilston)	ABB	Detailed protection studies (DTU)	PSCADX4	Apr-18
2	Synchronous compensator (Generic)	DTU	System studies (SPEN/UoS)	Pow erFactory 15.2.5	Jun-18
3	Statcom (Generic)	ABB	System studies (SPEN/UoS)	Pow erFactory 15.2.5	Mar-18
4	Type 2 variant for phasor studies (Neilston)	ABB	SSTI (SPEN/UoS), System studies (UoS), Control interaction w ith	Pow erFactory 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 (SPEN/UoS)	Pow erFactory 15.2.5	Sep-19
7	Battery Energy Storage	DTU	System studies (SPEN/UoS)	Pow erFactory 15.2.5	Sep-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)	Pow erFactory 15.2.5	Jun-19
10	GB Dynamic system model (full model) - present state	NGET/SPEN	System studies (SPEN/UoS)	Pow erFactory 15.2.5	Jul-18
11	GB Dynamic system model (full model) - future state(s)	NGET/SPEN	System studies (SPEN/UoS)	Pow erFactory 15.2.5	Jul-18
12	GB Dynamic system model (reduced local equivalent) - present state	NGET	Dynamic performance studies in PSCAD (ABB), RTDS studies (ABB)	Pow erFactory 15.2.5	Jul-18
13	GB Dynamic system model (reduced local equivalent) - for tupe 4	NGET	System studies (DTU)	Pow erFactory 15.2.5	Jul-18
14	EFCC reduced model for studies w ith EFCC models	UoS	UoS studies in conjunction w ith provided ABB model	Pow erFactory 15.2.5	
15	HVDC model for Western Link	SPEN	UoS studies	Pow erFactory 15.2.5	Jun-18

Figure 8. Modelling requirements matrix

2.8 Knowledge Sharing and Stakeholder Engagement

The Phoenix dissemination strategy has been developed to ensure robust mechanisms are in place throughout the project to ensure relevant learning and knowledge is identified and shared effectively to key stakeholders and interested parties.

2.8.1 Stakeholder Event 2017

In July of 2017, the Phoenix Project team held a Stakeholder Engagement Event at The Technology & Innovation Centre in Glasgow. Colin Taylor, Director of Engineering Services at SPEN opened the event by explaining that emerging network challenges mean there is a need for collaboration among industry partners and that the commercial innovation work stream in Phoenix will help answer some of the emerging questions regarding ancillary services market aid in creation of right market signals for investment in synchronous condenser /hybrid synchronous condenser technology.

The event was well-attended by industry experts ranging SO to vendors and independent consultants, where many interesting debates where ignited such as how Phoenix would be financed in the future, how regulatory changes may affect its success and the ownership of the system.

Attendees were greeted to a ‘live trial’ of Phoenix, which was designed to demonstrate SPEN’s vision of how the H-SC could support the future grid. Stakeholders praised the “informative presentations and very open panel discussion” and declaring it “technically very good.”

2.8.2 CIGRE Papers

From the proposal development and recent initial research, the University of Strathclyde disseminated some of the learning from the system studies. Their research was disseminated through papers which were submitted too and presented at CIGRE events;

- CIGRE B5 Colloquium, September, 2017, paper "Application of synchronous compensators in the GB transmission network to address protection challenges from increasing renewable generation"
- CIGRE UK Next Generation Network 10 Year Anniversary event, Manchester, October 2017, poster presentation on demonstrating the potential benefits of deploying SC in the GB transmission network

In the coming months the project team will:

- Establish a knowledge dissemination coordinator who will refine and update the dissemination strategy throughout the course of the project to maximise the benefits of Phoenix for all stakeholders. They will be responsible for identifying dissemination opportunities, ensuring all dissemination is consistent with the Phoenix identity, liaising with other relevant projects, maintaining an up to date list of stakeholders and establish contacts within them;
- Identify project champions within each relevant department who ensure the project remains visible and relevant to their department. These project champions need not be a part of the core project team;
- Prepare a range of materials (e.g. posters, presentations, leaflets and videos) that clearly define what Phoenix is and what the goals and benefits are. These materials will include different versions; each of which are tailored for audiences with a different level of technical and commercial knowledge;
- Establish an online portal to serve as the hub for conference papers, journals, documents etc.

The following knowledge dissemination matrix is used to support knowledge dissemination activities by ensuring important stakeholders are identified and engaged effectively through the course of the project.

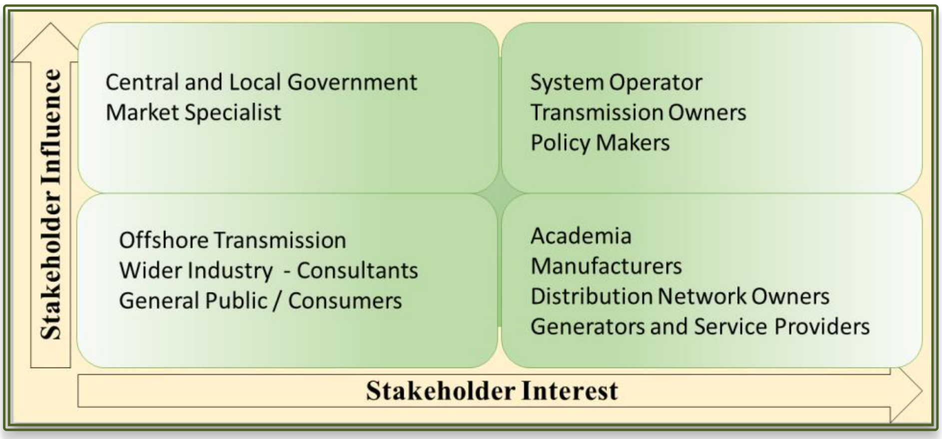


Figure 9. Phoenix Stakeholder Matrix

In order to ensure the stakeholders remain engaged and informed a number of key activities have been identified that will be conducted and assessed on an annual cycle, including:

- Biannual stakeholder events to notify and educate stakeholders;
- Biannual progress reports and marketing material to be circulated amongst stakeholders;
- Provisions for attendance and presentations at key industry innovation events;
- Continuous improvement of dissemination effectiveness

2.9 Outlook to the Next Reporting Period

Looking ahead to the next six months, the following activities are expected:

- Agree terms and complete contractual negotiations with NGET
- Conclude negotiations to recruit an Independent Market Specialist
- The design team will continue to develop the final detailed design
- A project collaboration portal is required to enable secure sharing and version tracking of documents throughout the project, such as design documents, project reports, and minutes of meetings, and will be procured in the coming months.
- Forthcoming Project Delivery Team meetings to be organised and attended in accordance to work package requirements.
- Detailed Knowledge Dissemination plan and training programme to be developed and agreed between all parties, defining the roles and responsibilities for annual participation and contribution of all project partners.

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

1. Technical workshops covering the operating principles of the H-SC, hosted by the Project Team
2. Site visit to DTU testing and simulation facilities, to be arranged

3 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, resource allocation and programme, however as previously mentioned the project schedule has been adjusted and agreed with all partners to combat the contractual delays we suffered in 2017.

4 Risk Management [Confidential]

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4.2.1 Key Technical and Roll-Out Risks

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5 Successful Delivery Reward Criteria (SDRC)

The Successful Delivery Reward Criteria 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.

Table 3 lists all the required evidences in line with project direction for reporting period.

Table 3. Achieved SDRC in reporting period

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.	**SDRC 1.2.** 1. Report on environmental studies and life cycle analysis. WP1 (01/12/2017). 3. Report on detailed installation diagrams and site layouts. WP1 (01/02/2017).
8) Knowledge Dissemination Stakeholder engagement and dissemination of learnings and outcomes of the pilot H-SC demonstration through project.	4. Project Phoenix regular project progress reports. WP6

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

Table 4. SDRC due in forthcoming period, accounting for the delays as previously mentioned.

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 (01/12/2017).
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	1. Cost benefit analysis model for SCs and H-SCs. WP3 (01/06/2018).

ancillary services provided by SCs. Create recommendations for regulatory considerations for future roll-out of SCs/H-SCs.	
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 (01/06/2017). 2. Report on output of SCAPP project on protection and control of synchronous condenser and simulation results of new control methods. WP4 (01/06/2018).
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 (01/12/2017). 3. Report on co-simulation for faster prototyping for new designs and controls. WP5 (01/12/2017).
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 (01/06/2018). 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 (01/06/2018).
8) Knowledge Dissemination Stakeholder engagement and dissemination of learnings and outcomes of the pilot H-SC demonstration through project.	4. Project Phoenix regular project progress reports. WP6

6 Learning Outcomes

During the reporting period, the contract negotiations have formed the largest part of the project and, as such, there have been no substantial learning outcomes to date however, with the detailed design and model development now underway, we anticipate key learning related to final design and operation during the forthcoming period.

7 Business Case Update

We are not aware of any developments that have taken place since the issue of the Project Direction that affect the business case for the Project.

8 Bank Account

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9 Intellectual Property Rights (IPR) [CONFIDENTIAL]

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10 Other

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11 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: [signature]

Name (Print): MICHAEL WYND

Title: HEAD OF NETWORK TECHNICAL SERVICES

Date: 2/2/18

Signature: [signature]

Name (Print): JAMES YU

Title: Future Networks Manger

Date: 2/Feb/2018

12 Appendices

12.1 Appendix 1 - Bank Account Statement

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12.2 Appendix 2 - Phoenix Successful Delivery Reward Criterion

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	1. Report on System Studies and Quantification of overall benefits from application of SCs/H-SCs in GB system. WP5

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 4. GB roadmap for roll-out of SCs/H-SCs. WP5
6) Pilot Installation and Operational Trial On-site installation and commissioning of pilot H-SC demonstration. Civil work and electrical connection of H-SC to the transmission network.	1. Report on site installation process, details and 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. Project Phoenix Close down report. WP6 4. Project Phoenix regular project progress reports. WP6.

12.3 Appendix 3 - Project Risk Register (Confidential)

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