NETWORK INNOVATION COMPETITION

PROJECT PROGRESS REPORT

JUNE 2016

ANGLE-DC

Version:	1.0	
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SECTION 1 EXECUTIVE SUMMARY

1.1. Project Background

The Angle-DC project is funded through Ofgem's Network Innovation Competition (NIC). Angle DC commenced in January 2016 and will be completed by April 2020. The project will demonstrate a smart and flexible method for reinforcing distribution networks by converting Alternating Current (AC) assets for Direct Current (DC) operation. Angle-DC will adapt existing power electronic technologies to build a Medium Voltage DC (MVDC) link which could be an effective solution to facilitate the integration of renewable resources and accommodate future demand growth.

This report details the progress of the Angle-DC project, focusing on the 1st 6-months of the project, January to June 2016. It also details work due to be carried out over the next 6-months of the project.

1.2. Project Progress Highlights

The overall project is divided into 6 distinct work packages and the Project's managers' report separates the project progress by these key areas.

The Angle-DC project team structure has been finalised, with Kevin Smith of SP Energy Networks selected as the Principal Project Manager. Work to select and invite the Project Steering Board members has also been completed. In addition to the formation of the Angle-DC Steering Board, Cardiff University was selected as the project academic partner.

Work Package 1 – Detailed Design

Progress has been made on the detailed systems analysis, MVDC market research, tender documentation and the Technical Specifications for the Holistic Circuit Condition Monitoring (HCCM) system and MVDC converters.

The detailed systems analysis results have identified real power set points for the control response of the MVDC link to changing network conditions. Supplier Pre-Qualification Questionnaire feedback, as part of the MVDC market research, has driven the project to bring the HCCM and MVDC link tender documentation development forward. This documentation was finalised and publish in May 2016 on the Achilles Vender Database. The HCCM monitoring Technical Specification was published in June 2016.

Work Package 2 – MVDC Link

The procurement and vendor evaluation for the MVDC link began in May 2016, with the publication of the tender documentation. The tender period shall conclude in July 2016, providing suppliers 2-months to compile and send their bids to SP Energy Networks.

During the next 6-months, a 5-month bid evaluation will take place, followed by the drafting of the procurement contract with the selected supplier. This process is planned to conclude in December.

Work Package 3 – AC System

A two part route feasibility study is being carried out. The first part is focused on drafting a route from Llanfair PG to Bangor substations. The second part has focused on gaining permission from the Britannia Bridge owner, Network Rail, to lay the cable on the spare track way. Work on this study is currently on schedule.

Following the study, work on the cable procurement and gaining the identified wayleaves and consents will form most of WP3 activity between June and December 2016.

Work Package 6 – Knowledge Dissemination

Two abstracts have been submitted to the 13th international conference on AC and DC Power Transmission, one on the MVDC link operational envelope study described in this progress report. The two papers are due to be presented at the conference in February 2017. Findings in this paper will also be presented at LCNI 2016 in November.

1.3. Business Case

As of May 2016, there has been no change to the business case of the project. By December 2016, the cost for both the HCCM systems and MVDC link will be known and should inform any amendments to the business case in the next 6-month progress report.

1.4. Learning Outcomes

Learning points are reviewed by the Angle-DC Project team at regular meetings to establish what was learned from the activities undertaken. At this stage early stage of the project, no formal learning outcomes have been published. The following learning outcomes are detailed in Section 8 of this report:

MVDC Converter Development: We have learned through the PQQ process that the range of development times for MVDC converter equipment can vary considerably.

MVDC Link Real and Reactive Power Setpoints: Through the work carried out on the MVDC link operational envelope studies (see Section 2.2.1); we have learned that a simple real power setpoint scheme can provide satisfactory control of the MVDC

From power flow study results, we have learned the MVDC link will be capable of keeping the voltage level within limits even in the N-1 scenario of the loss of the Bangor GT. The ±15-20 MVAr of reactive support at both ends of the link appear to be sufficient to manage the steady state voltage requirements on both sides of the Menai Strait.

DC Holistic Circuit Condition Monitoring:

Through the tender evaluation process, the project has learned that the HCCM system requires some in-project development to detect DC partial discharge.

1.5. Key Risks

At this stage, many of the risks have not had time to arise but still have an opportunity to do so. Section 10 of this report contains the current risks associated with successfully delivering Angle - DC as captured in the Risk Register including the risks captured in the last six-months.

The first key risk is the exclusion of the most appropriate MVDC converter supplier during the tendering exercise. The second key risk is unsuccessfully stimulating suppliers to develop MVDC converter market solutions between now and end of the project.

The final key risk is the route feasibility of the back-up AC circuit across the Britannia Bridge. Should Network Rail not accept this route option or the application of DC to the existing circuits, the only other option would be a crossing using directional drilling under the Menai Straight. The costs for this option would be significantly higher than for the Britannia Bridge AC cable route.

SECTION 2 PROJECT MANAGER'S REPORT

The last six months period has seen progress in a number of areas against the plan. The overall project is divided into 6 distinct work packages which enable the Angle-DC solution and provide valuable learning to the UK electricity industry. The progress and details of each of the work packages is set out in this section.

2.1. Project Setup

The Angle-DC project team structure has been finalised, with Kevin Smith of SP Energy Networks selected as the Principal Project Manager. Work to select and invite the Project Steering Board members has been completed, with the first Steering Board meeting being held at the Welsh Government buildings in Llandudno Junction in June 2016. The Steering Board acts as executive direction to the delivery of the Angle-DC Project and offers project guidance to find more effective ways of overcoming key project challenges. Steering board members organisations comprise of local and national Welsh Government, a leading Welsh academic institution and the SP Energy Networks Project Board.

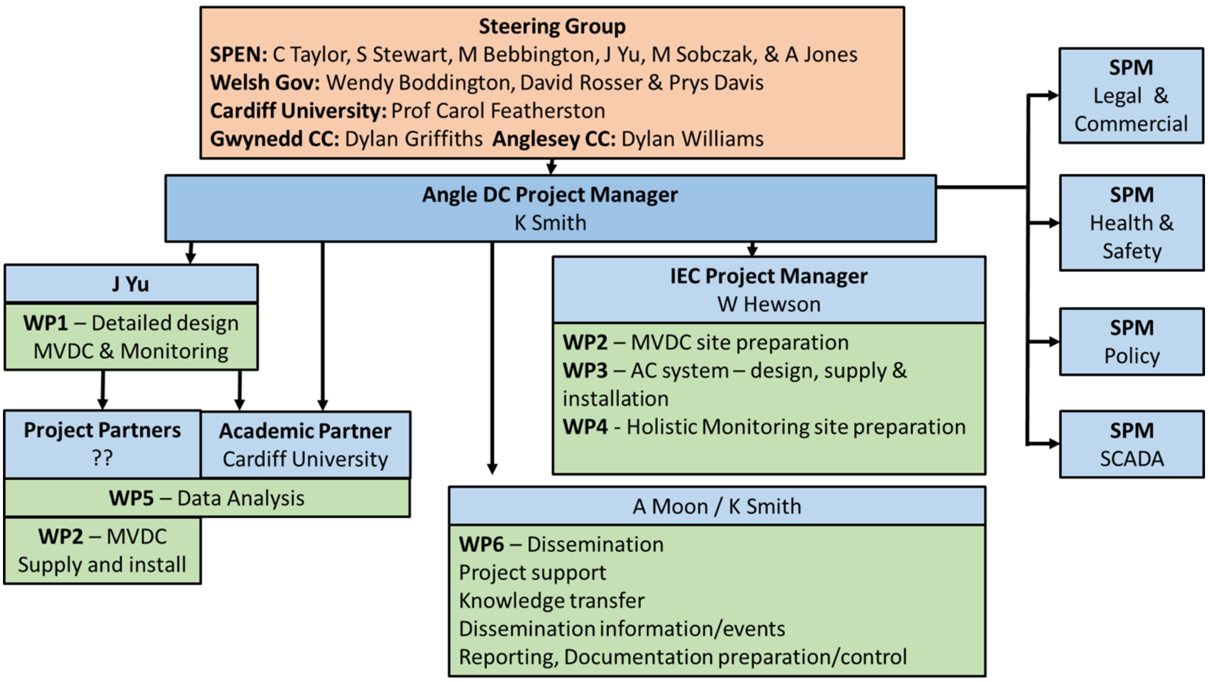


Figure 1. Angle - DC project structure.

In addition to the formation of the Angle-DC Steering Board, the selection of an academic partner has been carried out. Four academic partners took part in an academic engagement call and were assessed based on their responses to key questions. The evaluation criteria used for the assessment were: suitable resources, workable plan and value for money. Of the four universities approached, Cardiff University was selected as the academic partner. Since selection, Cardiff University and the Project team have been drawing up a collaboration agreement, a scope and schedule of works. In parallel to this activity, work on the first work package has been also been progressed.

2.2. Work Package 1 – Detailed Design

Cable capability evaluation was carried out in May 2015 at Bangor Substation by HVPD LTD to assess if the two existing ac circuits could be converted from ac to dc operation. The tests included Insulation Resistance (IR), on-line Partial Discharge (OLPD), Very Low Frequency (VLF) withstand with PD, DC withstand with PD and Time Domain Reflectometry (TDR). All tests passed, with the cable insulation result showing a general good insulation condition without severe localised defects. Recommendations for further testing included a further OLPD test at the Llanfair PG substation end, repeated testing at higher voltages (57 kV) and a testing of service-aged cable samples of similar insulation type(s) in laboratory conditions. Following a review in April 2016, further capability evaluation was deemed to be of limited value and possibly insufficient to fully evaluate the double circuit cable and therefore further cable tests will not be undertaken.

During the first 6-months for the project, progress has been made in four key areas, these are: a detailed systems analysis, development of the tender documentation, development of the technical specifications for the Holistic Circuit Condition Monitoring (HCCM) systems and a Medium Voltage Direct Current (MVDC) converter market research update.

2.2.1 Detailed Systems Analysis

The work on the detailed systems analysis has consisted of development of the control strategy and harmonic analysis of the network.

Control Strategy

The overall control strategy of the MVDC link is envisaged to consist of the following:

1) MVDC Voltage Source Converter (VSC) Controller: voltage and power control of the MVDC converters
2) Automated Constraint Management (ACM): Management of Bangor Grid Transformer (GT) outage
3) Local Control Response: control of the MVDC link within a derived operational envelope
4) Central Control Scheme: Further optimisation of the setpoint from wider SCADA data

Progress on the local control response has been made by carrying out one power flow study for each combination of Anglesey generation, demand and network scenarios (normal & fault) and combining them into one MVDC operational envelope study. The study considered a number of operating scenarios, i.e. a sensitivity sweep, by modelling all combinations of:

- **Demand levels**: the range considered demand on Anglesey operating at the following: minimum demand, summer maximum, existing maximum, and maximum demand forecasted at end ED1

- **Generation levels**: the range considered the levels on Anglesey between 0 MW and maximum generation capacity. This maximum included connected and contracted generation
- **MVDC link real power setpoints**: the MVDC link was considered to operate in voltage control mode with a ±25 MW real power flow capability. The Real-power set-point levels have been considered in 5 MW increments between -25 MW to +25 MW
- **Network Scenarios (Normal and fault conditions)**: under all combinations of the above demand and generation scenarios with each MVDC setpoint, an N-1 analysis was undertaken considering outages of each Grid Transformer and EHV circuit on Anglesey. This assessed whether there is a risk of thermal overload or voltage excursion due to an event on the system when operating at each individual MW setpoint level.

The results were collated summarised to indicate the N-1 operational envelope within which the MVDC link can be expected to operate.

A network losses study was carried out with the aim of finding the optimum real-power setpoint for the MVDC link which would minimise network losses under each generation and demand scenario used in the operational envelope study, under normal network conditions.

The results from the operational envelope and network losses studies were compared to assess whether the MVDC optimal setpoints could be used in each combination of demand level, generation level and network scenario and not breach either the: over-voltage, under-voltage limits or network thermal constraints. The studies comparisons indicate that during maximum demand, minimum generation, for almost all network conditions, the optimal setpoint is a +20 MW (import). During minimum demand, maximum generation, for all network conditions, the optimal setpoint is -5 MW (export). The only network condition exception is when maximum demand and minimum generation occur and there is a loss of the Bangor GT. Instead of a + 20 MW setpoint, the MVDC link should ramp to zero. The exact ramp rate is yet to be determined, but should occur on an mS timescale to avoid breaching under-voltage limits.

Between June and December 2016 transient network studies will be carried out to understand a suitable ACM response, establishing the required MVDC converter ramp rates when responding to a fault at the Bangor GT. Development of a central a control scheme and associated telecommunication requirements will also form a part of the detailed systems analysis work over the next reporting period.

All studies described above were carried out by power system analysis consultancy TNEI on behalf of the Project. Dissemination activity on the learning and key findings derived from the detailed systems analysis studies is described in Section 2.7.

Harmonic Analysis

Harmonic analysis of the Anglesey network has to date consisted of collection of 2-weeks of harmonic background data up to and including the 24th harmonic. This information has been added to the MVDC invitation to tender documentation. Further work on harmonic analysis will be carried out in June 2016, which will consist of deriving harmonic impedance loci at identified critical bus bars for each operational scenario assessed in the operational envelope study. This information will be of use to suppliers, identified in the MVDC market research update, for accurately costing their bid submissions.

2.2.2 MVDC Market Research Update

A two stage Pre-Qualification Questionnaire (PQQ) was carried out to assess the suitability of the MVDC converter suppliers in terms commercial, technical and financial capability. This was carried in the first two months of 2016. Some established HVDC suppliers declined to participate in the PQQ or tender process. Of the suppliers that took part, 4 were identified for the tendering stage and some indicated they would need up to 24-months to fabricate, test, deliver and commission the MVDC converters; an additional 6-months than anticipated in the original program. The PQQ work has been concluded and has informed amendments to the MVDC tender documentation development program.

2.2.3 Development of Tender Documentation

The procurement of the MVDC link is critical to the Angle – DC project and affects a number of different project deliverables, including the design and final control strategy. Due to supplier responses in the PQQ, the procurement of the MVDC link has been brought forward from the original submission program to allow for the extra lead time. Because of this, development of the tender documentation for the MVDC link and HCCM systems was completed by April 2016.

Further work on the development of the MVDC converter tender documentation will involve providing suppliers with harmonic impedance loci and Electromagnetic Interference (EMI) limits during the tender period, to help them accurately cost harmonic filters if they are required.

2.2.1 Development of Technical Specifications

The accelerated procurement program for HCCM system has allowed the technical specification to be informed by the capabilities of the selected supplier, specifically regarding the monitoring of DC partial discharge. The specification has now been written and shared with project stakeholders as detailed in Section 7.1.1.

Over the next 6-months, work on Technical Specification development will shift to the MVDC converters. It is expected this technical specification will also be informed by the detailed design of the selected MVDC converter supplier as well as the design work described in Section 2.2.

2.3. Work Package 2 – MVDC Link

The procurement and vendor evaluation for the MVDC link began in May 2016, with the publication of the tender documentation. The four suppliers, identified in the PQQ stage, recently took a tour of Llanfair PG and Bangor circuit and took part in ½-day one to one sessions with the Angle-DC Project team and an external HVDC expert from Parsons Brinckerhoff; an advisor to the project. The tender period will conclude in July 2016, providing suppliers 2-months to compile and send their bids to SP Energy Networks.

During the next 6-months, a 5-month bid evaluation will take place, followed by the drafting of the procurement contract with the selected supplier. This process is now due to conclude in early December, 8-months ahead of the original program. This will allow a longer lead for manufacture and deployment of the MVDC link. For MVDC manufacturing and deployment; the original program allowed just under 20-months, this has now been extended to 23-months, with additional time allowed as contingency in case of any development issues with MVDC fabrication and deployment. The installation of the MVDC link is scheduled to begin within 1-month of commissioning of the AC back-up circuit as part of WP 3.

2.4. Work Package 3 – AC System

The back-up AC circuit needs to be commissioned before the MVDC converters to enable testing of the MVDC link under commissioning and ensure the security of the network during the MVDC converter installation. This work has been brought forward due WP2 outperformance procuring the MVDC converters and to allow a route feasibility study to be concluded before the AC system detailed circuit design stage. Two parts of the study are being carried out in parallel, with the first part focused on drafting a route from Llanfair PG to Bangor substations and identifying the wayleaves and consents needed for the additional circuit to be laid. The second part of the study has focused on gaining permission from the Britannia Bridge owner, Network Rail, to lay the cable on the spare track way. Early dialogue with Network Rail was started in mid-February 2016 and the route feasibility study is scheduled for conclusion in September 2016.

Following the study, work on the cable procurement and gaining the identified wayleaves and consents will form most of WP3 activity between June and December 2016. Commissioning of the HCCM systems does not require the AC back-up circuit to be operational, due to a planned 12-month period of pre DC conversion monitoring of the original AC circuit.

2.5. Work Package 4 – Holistic Circuit Condition Monitoring Systems

To retain the 12-month pre-DC conversion monitoring period, due to the accelerated MVDC procurement program, conclusion of the HCCM systems procurement has been brought forward from December 2016. The invitation to tender documentation was published mid-April 2016. Six suppliers were invited to tender; during this period each supplier was invited to take a tour of Llanfair PG and Bangor circuit and take part in one to one sessions with the Angle-DC Project team. Following the conclusion of the tender submission period in early May 2016, a 4-week bid evaluation has now taken place. The contract is due to be awarded to the selected supplier at the end of June 2016, 6-months ahead of the original program date.

Over the next 6-months, the selected supplier will have until the end of 2016 to fabricate the monitoring equipment and pass it through factory acceptance testing. Once equipment production has been carried out, preparation of the substations, to accommodate the HCCM equipment, will be carried out into the 1st quarter of 2017. Once installed, data from the HCCM systems will be used by our academic partner to deliver elements of Work Package 5.

2.6. Work Package 5 – Data Analysis and Enhanced Learning

Collection of HCCM data will from a part of Work Package 5. This data will be analysed and interpreted by our academic partner, HCCM systems supplier and then reviewed by SP Energy Networks. Since the HCCM systems will not be commissioned until the 3rd reporting period, no progress on HCCM data analysis has yet occurred.

In addition to HCCM data analysis, enhanced learning through live tests on the MVDC performance, including control of the power flow and voltage, will take place following installation of the MVDC-link. Since installation will occur between Q4 2018 and Q2 2019, progress in the task area is yet to take place.

2.7. Work Package 6 – Knowledge Dissemination

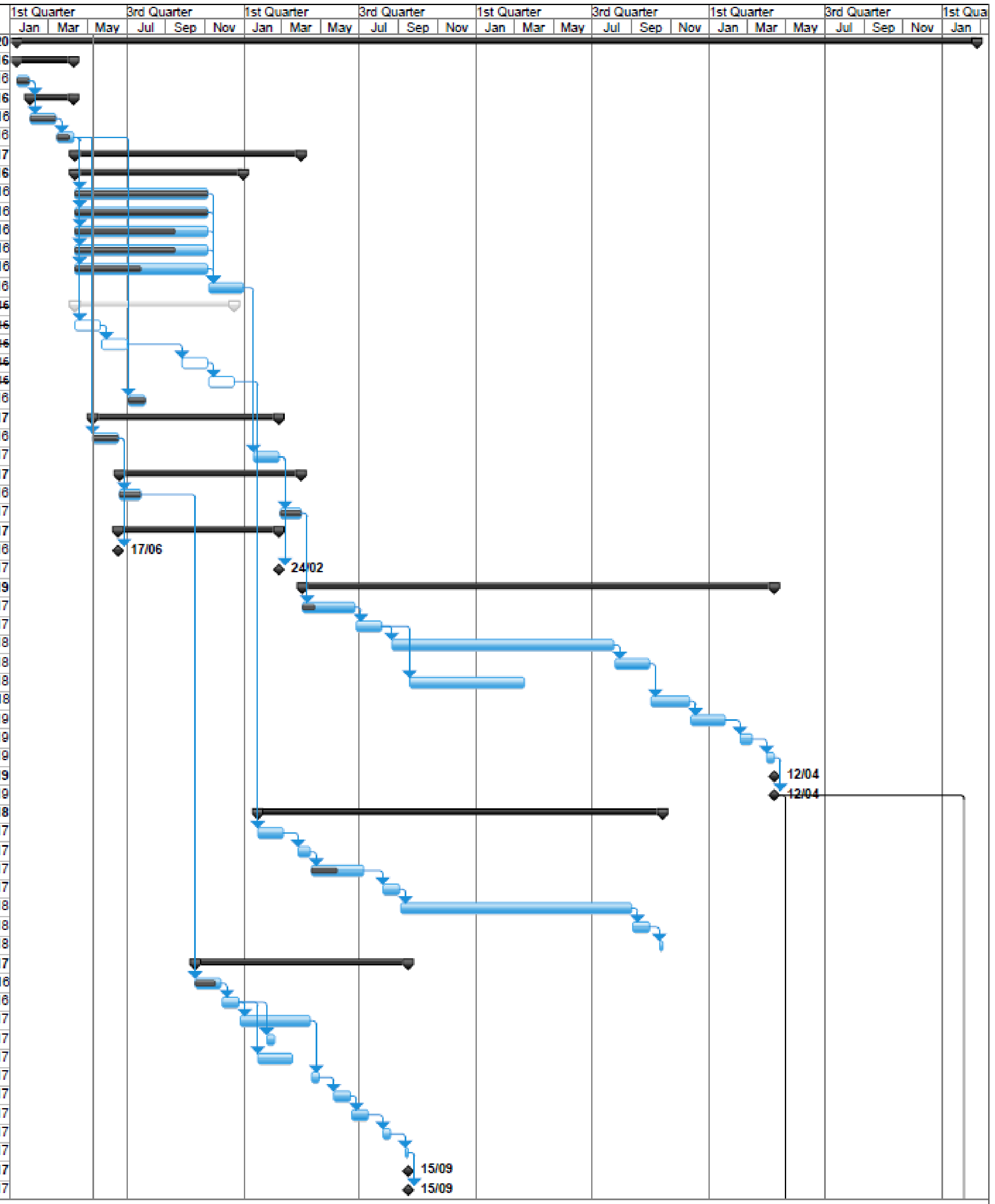
In addition to the 6-monthly progress report and website update, two abstracts have been submitted to the 13th international conference on AC and DC Power Transmission, one on the MVDC link operational envelope study described in Section 2.2.1. Two papers written by consultants at Parsons Brinckerhoff and TNIE, together with SP Energy Networks, are due to be submitted before October 2016. These shall be presented at the conference in February 2017. Findings in this paper will also be presented at LCNI 2016 in November.

SECTION 3 BUSINESS CASE UPDATE

As described in Section 2.5, the HCCM systems cost will not be clear until the end of June 2016. Therefore, as of May 2016, there has been no change to the business case of the project. By December 2016, the cost for both the HCCM systems and MVDC link will be known and should inform any amendments to the business case in the next 6-month progress report.

SECTION 4 PROGRESS AGAINST PLAN

ID		Task Name	Duration	Start	Finish
1		**ANGLE-DC**	**1077 days**	**Mon 11/01/16**	**Mon 24/02/20**
2		**Project setup**	**65 days**	**Mon 11/01/16**	**Fri 08/04/16**
3	✓	Project initiation document	15 days	Mon 11/01/16	Fri 29/01/16
4		**Formalise team structure: Project manager, Project board, Delivery team**	**50 days**	**Mon 01/02/16**	**Fri 08/04/16**
5	✓	Identify project partners	30 days	Mon 01/02/16	Fri 11/03/16
6		Develop collaboration agreement with project partners	20 days	Mon 14/03/16	Fri 08/04/16
7		**WP1 - Detailed design**	**255 days**	**Mon 11/04/16**	**Fri 31/03/17**
8		**Detailed system analysis**	**190 days**	**Mon 11/04/16**	**Fri 30/12/16**
9	✓	Generation, demand scenarios analysis	150 days	Mon 11/04/16	Fri 04/11/16
10	✓	Normal and fault conditions analysis	150 days	Mon 11/04/16	Fri 04/11/16
11		Harmonic analysis	150 days	Mon 11/04/16	Fri 04/11/16
12		Development of control strategy	150 days	Mon 11/04/16	Fri 04/11/16
13		Development of protection strategy	150 days	Mon 11/04/16	Fri 04/11/16
14		Q&A and approval	40 days	Mon 07/11/16	Fri 30/12/16
15		~~Cable capability evaluation~~	~~180 days~~	~~Mon 11/04/16~~	~~Fri 16/12/16~~
16		~~Development of test specification~~	~~30 days~~	~~Mon 11/04/16~~	~~Fri 20/05/16~~
17		~~Procurement for cable test~~	~~30 days~~	~~Mon 23/05/16~~	~~Fri 01/07/16~~
18		~~Cable capability test~~	~~30 days~~	~~Mon 26/09/16~~	~~Fri 04/11/16~~
19		~~Cable capability evaluation report~~	~~30 days~~	~~Mon 07/11/16~~	~~Fri 16/12/16~~
20	✓	MVDC market research update	20 days	Mon 04/07/16	Fri 29/07/16
21		**Development of technical specifications**	**210 days**	**Mon 09/05/16**	**Fri 24/02/17**
22	✓	Develop holistic condition monitoring equipment technical specification	30 days	Mon 09/05/16	Fri 17/06/16
23		Develop MVDC link technical specification	30 days	Mon 16/01/17	Fri 24/02/17
24	✓	**Develoment of invitation to tender documents**	**205 days**	**Mon 20/06/16**	**Fri 31/03/17**
25	✓	Develop invitation to tender documents for holistic condition monitoring equipment	25 days	Mon 20/06/16	Fri 22/07/16
26	✓	Develop invitation to tender documents for MVDC link	25 days	Mon 27/02/17	Fri 31/03/17
27		**SDRCs**	**180 days**	**Fri 17/06/16**	**Fri 24/02/17**
28	✓	Publication of technical specification for monitoring system	0 days	Fri 17/06/16	Fri 17/06/16
29		Publication of technical specification for the MVDC link	0 days	Fri 24/02/17	Fri 24/02/17
30		**WP2 - MVDC Link**	**530 days**	**Mon 03/04/17**	**Fri 12/04/19**
31		Procurement and vendor evaluation	60 days	Mon 03/04/17	Fri 23/06/17
32		Sign the contract	30 days	Mon 26/06/17	Fri 04/08/17
33		Equipment production	250 days	Mon 21/08/17	Fri 03/08/18
34		Factory acceptance test	40 days	Mon 06/08/18	Fri 28/09/18
35		Site preparation, civil, communications and electrical	130 days	Mon 18/09/17	Fri 16/03/18
36		Equipment delivery	45 days	Mon 01/10/18	Fri 30/11/18
37		Equipment installation	40 days	Mon 03/12/18	Fri 25/01/19
38		Site acceptance test	15 days	Mon 18/02/19	Fri 08/03/19
39		Commissioning	10 days	Mon 01/04/19	Fri 12/04/19
40		**SDRCs**	**0 days**	**Fri 12/04/19**	**Fri 12/04/19**
41		Installation of MVDC link	0 days	Fri 12/04/19	Fri 12/04/19
42		**WP3 - AC System**	**455 days**	**Mon 23/01/17**	**Fri 19/10/18**
43		Detailed circuit design	30 days	Mon 23/01/17	Fri 03/03/17
44		Procurement	15 days	Mon 27/03/17	Fri 14/04/17
45		Wayleaves	60 days	Mon 17/04/17	Fri 07/07/17
46		Equipment delivery	20 days	Mon 07/08/17	Fri 01/09/17
47		Installation	260 days	Mon 04/09/17	Fri 31/08/18
48		Protection settings	20 days	Mon 03/09/18	Fri 28/09/18
49		Commissioning	5 days	Mon 15/10/18	Fri 19/10/18
50		**WP4 - Holistic Condition Monitoring**	**240 days**	**Mon 17/10/16**	**Fri 15/09/17**
51		Procurement and vendor evaluation	30 days	Mon 17/10/16	Fri 25/11/16
52		Sign the contract	20 days	Mon 28/11/16	Fri 23/12/16
53		Equipment production	80 days	Mon 26/12/16	Fri 14/04/17
54		Factory acceptance test	10 days	Mon 06/02/17	Fri 17/02/17
55		Site preparation	40 days	Mon 23/01/17	Fri 17/03/17
56		Equipment delivery	10 days	Mon 17/04/17	Fri 28/04/17
57		Equipment installation	20 days	Mon 22/05/17	Fri 16/06/17
58		Communications	20 days	Mon 19/06/17	Fri 14/07/17
59		Site acceptance test	10 days	Mon 07/08/17	Fri 18/08/17
60		Commissioning	5 days	Mon 11/09/17	Fri 15/09/17
61		**SDRCs**	**0 days**	**Fri 15/09/17**	**Fri 15/09/17**
62		Commissioning of Holistic Condition Monitoring systems	0 days	Fri 15/09/17	Fri 15/09/17

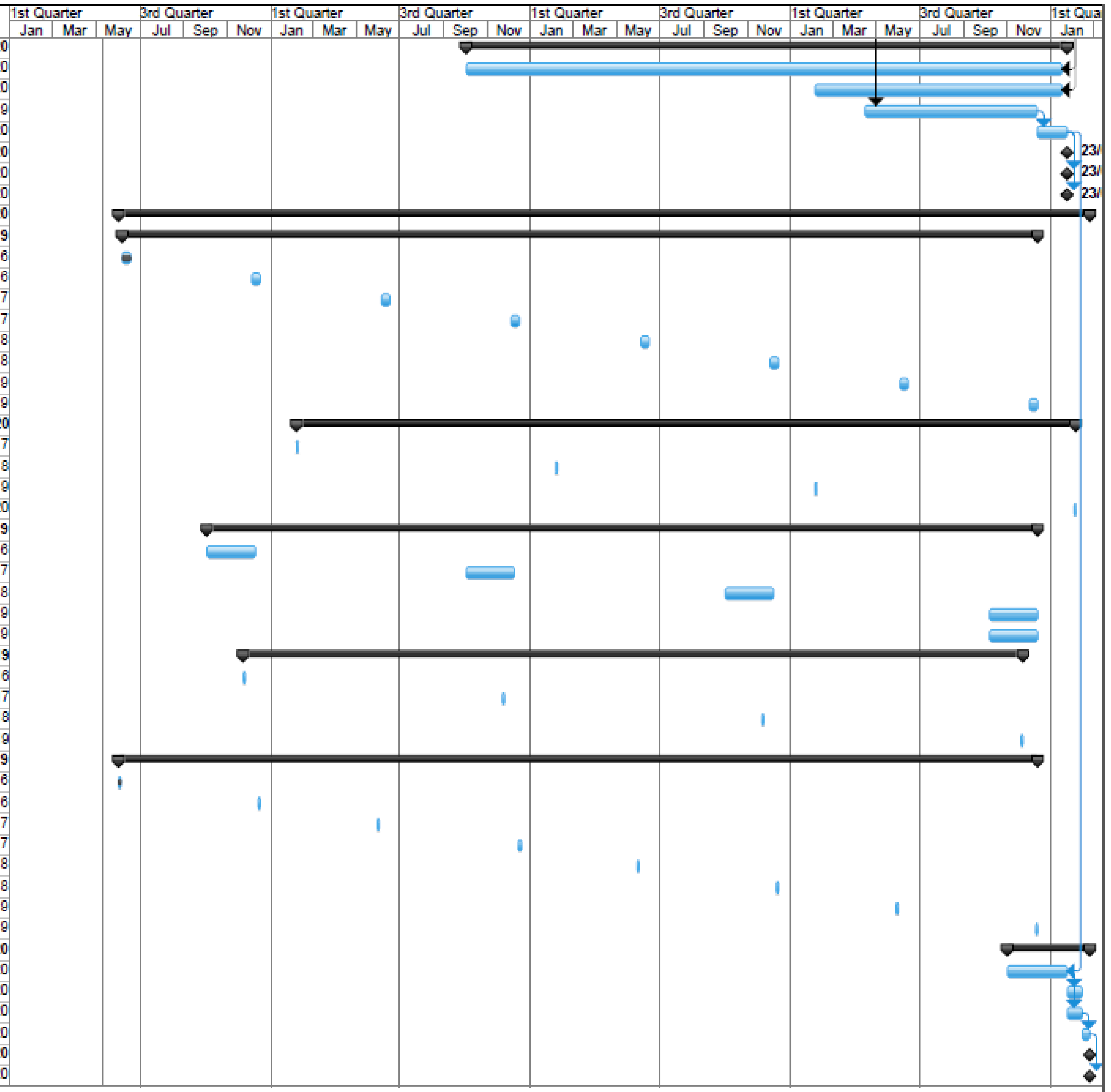


Project: ANGLE-DC Project Plan
Date: Wed 11/05/16

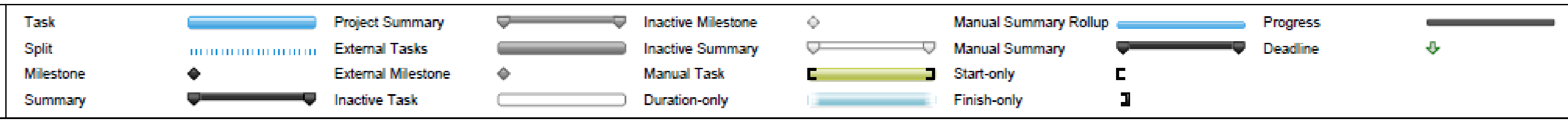
Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Progress | Deadline

ANGLE-DC

ID		Task Name	Duration	Start	Finish
63		**WP 5 - Data Analysis**	**605 days**	**Mon 02/10/17**	**Thu 23/01/20**
64		Gather Holistic Condition Monitoring data	600 days	Mon 02/10/17	Thu 16/01/20
65		MVDC system setting adjustments	250 days	Mon 04/02/19	Thu 16/01/20
66		Develop policy documents for MVDC applications	175 days	Mon 15/04/19	Thu 12/12/19
67		Report writing	30 days	Fri 13/12/19	Thu 23/01/20
68		**SDRCs**	**0 days**	**Thu 23/01/20**	**Thu 23/01/20**
69		Publication of Holistic Condition Monitoring data	0 days	Thu 23/01/20	Thu 23/01/20
70		Publication of operation performance of MVDC converters	0 days	Thu 23/01/20	Thu 23/01/20
71		**WP 6 - Dissemination**	**975 days**	**Wed 01/06/16**	**Mon 24/02/20**
72		**6 monthly progress report**	**921 days**	**Mon 06/06/16**	**Fri 13/12/19**
73	✓	Report 1	10 days	Mon 06/06/16	Fri 17/06/16
74		Report 2	10 days	Mon 05/12/16	Fri 16/12/16
75		Report 3	10 days	Mon 05/06/17	Fri 16/06/17
76		Report 4	10 days	Mon 04/12/17	Fri 15/12/17
77		Report 5	10 days	Mon 04/06/18	Fri 15/06/18
78		Report 6	10 days	Mon 03/12/18	Fri 14/12/18
79		Report 7	10 days	Mon 03/06/19	Fri 14/06/19
80		Report 8	10 days	Mon 02/12/19	Fri 13/12/19
81		**Workshops**	**783 days**	**Mon 06/02/17**	**Tue 04/02/20**
82		MVDC Technical Design	2 days	Mon 06/02/17	Tue 07/02/17
83		Real-Time Circuit Condition Monitoring	2 days	Mon 05/02/18	Tue 06/02/18
84		MVDC Manufacturing and Site Preparation	2 days	Mon 04/02/19	Tue 05/02/19
85		MVDC Link Performance Review	2 days	Mon 03/02/20	Tue 04/02/20
86		**Webinars**	**836 days**	**Mon 03/10/16**	**Fri 13/12/19**
87		MVDC technoloigy and Supplier Engagement	50 days	Mon 03/10/16	Fri 09/12/16
88		Real-Time Circuit Condition Monitoring systems for AC and DC applications	50 days	Mon 02/10/17	Fri 08/12/17
89		MVDC manufacturing	50 days	Mon 01/10/18	Fri 07/12/18
90		Cable ageing mechanism in AC and DC conditions	50 days	Mon 07/10/19	Fri 13/12/19
91		MVDC performance in real-life and data analysis	50 days	Mon 07/10/19	Fri 13/12/19
92		**LCNI conference**	**784 days**	**Wed 23/11/16**	**Fri 22/11/19**
93		LCNI 2016	3 days	Wed 23/11/16	Fri 25/11/16
94		LCNI 2017	3 days	Wed 22/11/17	Fri 24/11/17
95		LCNI 2018	3 days	Wed 21/11/18	Fri 23/11/18
96		LCNI 2019	3 days	Wed 20/11/19	Fri 22/11/19
97		**SPEN innovation website update**	**924 days**	**Wed 01/06/16**	**Fri 13/12/19**
98	✓	6 monthly update 1	3 days	Wed 01/06/16	Fri 03/06/16
99		6 monthly update 2	3 days	Wed 14/12/16	Fri 16/12/16
100		6 monthly update 3	3 days	Tue 30/05/17	Thu 01/06/17
101		6 monthly update 4	3 days	Thu 14/12/17	Mon 18/12/17
102		6 monthly update 5	3 days	Wed 30/05/18	Fri 01/06/18
103		6 monthly update 6	3 days	Wed 12/12/18	Fri 14/12/18
104		6 monthly update 7	3 days	Wed 29/05/19	Fri 31/05/19
105		6 monthly update 8	3 days	Wed 11/12/19	Fri 13/12/19
106		**Close-down report**	**82 days**	**Fri 01/11/19**	**Mon 24/02/20**
107		First draft preparation	60 days	Fri 01/11/19	Thu 23/01/20
108		Internal review	15 days	Fri 24/01/20	Thu 13/02/20
109		External consultation	15 days	Fri 24/01/20	Thu 13/02/20
110		Final submission	7 days	Fri 14/02/20	Mon 24/02/20
111		**SDRCs**	**0 days**	**Mon 24/02/20**	**Mon 24/02/20**
112		Effective Knowledge Dissemination	0 days	Mon 24/02/20	Mon 24/02/20



Project: ANGLE-DC Project Plan
Date: Wed 11/05/16



SECTION 5 PROGRESS AGAINST BUDGET

Below is a summary of the total project budget position from commencement to June 2016. The budget plan refers to the revised budget approved in the October 2014 project direction.

In line with the funding arrangements, SPM have contributed to costs incurred for a proportion of the expenditure in-line with the project direction. Costs for the NIC funded elements will be transferred from the bank account and a copy of the statement is included in **Error! Reference source not found.**.

Activity	Budget to Date (£k)	Actual to Date (£k)	Variance (£k)	Commentary
Labour	[redacted]	[redacted]	[redacted]	Some labour undertaken by contractors. IEC labour costs not yet received.
Equipment	[redacted]	[redacted]	[redacted]	
Contractors	[redacted]	[redacted]	[redacted]	Contractors used in place of internal labour.
IT	[redacted]	[redacted]	[redacted]	
Travel & Expenses	[redacted]	[redacted]	[redacted]	Necessary travel lower than plan.
Contingency & Others	[redacted]	[redacted]	[redacted]	No contingency required to date.
Totals	[redacted]	[redacted]	[redacted]	

Several of the costs for the project have yet to be incurred which is illustrated by the actual costs versus the budget to date.

SECTION 6 BANK ACCOUNT

A copy of the bank statement detailing the transactions of the project bank account since its creation is attached to this report. The figures in the statement relate to the NIC funded costs only and not the total project costs. The total debit from the NIC bank account is lower than the NIC element of project costs until the date of the next costs reconciliation. Minor differences in the reconciliation between costs and funding being transferred from the bank account are due to timing of transactions.

SECTION 7 SDRC

This section describes the work to date associated with the project SDRCs. Over the first reporting period, these SDRCs relate to development of the HCCM system and MVDC converter Technical Specifications.

7.1.1 Holistic Circuit Condition Monitoring Systems - SDRC 1 and SDRC 3

To achieve SDRC 1, the HCCM systems technical specification has been shared with all UK DNOs and iDNOs and local Welsh 3rd party supplier networks via Welsh Assembly Government website 'Sell2Wales'.

The technical specification has also been published on the Angle-DC Project websites. This documentation was made available as a digital download on the 17th of June 2016. The specification contains the Scope and Objectives, Functionality, Architecture and Design of the HCCM systems. SDRC 1 has therefore been achieved to program.

The HCCM system equipment production and some site preparation are scheduled to take place before December 2016 due to the procurement of the HCCM systems being brought forward by 6-months. The work leading to the commissioning of the HCCM systems is therefore expected to be ahead of the original program. This program outperformance will reduce any risks associated with commissioning of the HCCM systems by September 2017 to achieve SDRC 3.

7.1.2 MVDC Technical Specification – SDRC 2

The early procurement of the MVDC converters has provided an opportunity for the Technical Specification to be informed by the selected supplier. This Technical Specification will contain: scope and objectives, electrical specifications, control strategy and site installation requirements. To enable an accurate MVDC converter design, suppliers are to be provided with normal and fault conditions, harmonic background and network data. Further work on incremental harmonic voltage distortion, network impedance loci and EMI levels are scheduled to be concluded by July 2017 to feed into the MVDC converter filter design. Further work on site noise requirements will also take place by August 2016, which will feed into the site installation requirements of the Technical Specification.

The Technical Specification for the MVDC converters is due in February 2017. As described in Section 2.2, work on the local control strategy has been completed, which has provided some information on telecommunication requirements.

Table 1. SDRC progress summary

SDRC	Status	Due Date	Comments
SDRC 1 - Publication of HCCM Technical Specification.	Complete	17/06/2016	Shared with all relevant stakeholders.
SDRC 2 - Publication of Converter Technical Specification.	On Track	24/02/2017	Procurement brought forward, with Technical specification informed by design of selected supplier.
SDRC - 3 - Commissioning of HCCM system	On Track	15/09/2017	Not stared, but expected to be completed ahead of schedule.
SDRC 4 – Factory Acceptance Test of MVDC Converters.	On Track	28/09/2018	Not stared, but expected to be completed ahead of schedule.
SDRC - 5 Installation of MVDC Circuit/ Commissioning of Converters.	On Track	12/04/2019	Not stared, but expected to be completed ahead of schedule.
SDRC 6 - Publication of Holistic Condition Monitoring data.	On Track	23/01/2020	Not stared, but expected to be completed ahead of schedule.
SDRC 7 - Publication of operation performance of MVDC converters.	On Track	23/01/2020	Not stared, but expected to be completed ahead of schedule.
SDRC 8 - Effective Knowledge Dissemination.	On Track	16/04/2020	Website updated and 6-monthly project report has been published. Paper abstracts submitted to IET ACDC conference.

SECTION 8 LEARNING OUTCOMES

Learning points are reviewed by the Angle-DC Project team at regular meetings to establish what was learned from the activities undertaken. At this stage early stage of the project, no formal learning outcomes have been published to date. The following learning outcomes, over the 1st 6-months of the project, are a detailed as follows:

MVDC Converter Development: We have learned that the range of development times for MVDC converter equipment can vary considerably. To maintain a competitive procurement process, allowance for longer lead times should be given to suppliers considering the current Technology Readiness Level (TRL) of MVDC converter equipment.

MVDC Link Real and Reactive Power Setpoints: Through the work carried out on the MVDC link operational envelope studies (see Section 2.2.1), we have learned that a simple real power setpoint scheme can provide satisfactory control of the MVDC link without risking the network for all generation and demand states in almost all N-1 contingency scenarios on the North Wales network. An optimised power flow control scheme has been modelled based on reducing network losses. Other basis for optimisation will be assessed when exploring the feasibility of MVDC technology as a future enabler for a Distribution System Operator (DSO) model.

DC Holistic Circuit Condition Monitoring:

Through the tender evaluation process, the project has learned that the HCCM system requires some in project development to detect DC partial discharge.

SECTION 9 INTELLECTUAL PROPERTY RIGHTS (IPR)

The project is not funding the development of any technology which should create foreground IPR. Cardiff University and SP Energy Networks are due to sign a collaboration agreement by the end of June 2016. It is expected Partners will accept the NIC default IPR arrangements. We do not anticipate any further changes to this approach for any subsequent project partners.

SECTION 10 RISK MANAGEMENT

In order to ensure successful delivery of expected benefits and learning objectives of the ANGLE-DC Project, we proactively identify risks to the project and provide mitigation plans. The risk register is being updated regularly during the course of the project. All identified risks are list under four major risks areas (technical, procurement, operational and project management) and are listed in Table 2.

Two risks identified in the table have been updated with the current perception of the Project team. These are :-

Risk 2.04 The new additional 33kVAC circuit has been planned within the project submission for installation adjacent to the existing cables across the Britannia Bridge. Discussions with Network Rail have identified that they may have future plans to open a second track where the existing utilities are laid and this could affect the available space. Also any impact of the DC operation will have to be mitigated from the second track signalling and the possibility of any future electrification of the line. Therefore the risk of not obtaining consents for the new AC circuit and operation of DC on the existing cables has been increased to 25/40.

Risk 4.01 Should the problems of risk 2.04 materialise, then alternatives to the Britannia Bridge route for the new 33kVAC circuit and the possible DC operation of the existing cable circuits will have to be determined. Alternative routes were not included in the project budget and will incur an increase in costs. This risk has been increased to 20/40

Table 2. Project risk register.

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
1. Technical risks					
1.01	Existing cables integrity with DC	Cables are unsuitable for DC operation at 27kV either due to age or type.	Project halted; delayed reinforcement and no demonstration of conversion to MVDC.	1. System operating DC voltage level kept at or below peak AC voltage level (27kV). 2. Conductor temperature limited to a maximum of 50°C for all cables. 3. Short time 27kV DC testing completed on the circuit with no problems.	**5**
1.02	Existing cable joints integrity with DC	Joints are unsuitable for DC operation at 27kV due to age or type.	Project halted; delayed reinforcement and no demonstration of conversion to MVDC.	1. System operating DC voltage level kept at or below peak AC voltage level (27kV). 2. Conductor temperature limited to a maximum of 50°C for all cables types. 3. Short time 27kV DC testing completed on the circuit with no problems	**10**
1.03	Harmonic interference	Superimposed high frequency interference on MVDC in existing cables couples with third party services.	Delay and additional cost to project in order to resolve problems for third parties.	Perform a study of VSC converter harmonics and determine likely interference on telecom and transport signalling after a study of installed services and harmonics to be generated. VSC converter filters to be designed to be adequate by converter supplier.	**5**
1.04	Earthing with DC	High DC earth return currents.	Discontinued operation and additional cost to project to improve earthing arrangements.	VSC converter study required to determine the best converter arrangement for this application to reduce the level of earth return currents during normal and abnormal operation.	**5**

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
1. Technical risks					
1.05	Existing cables integrity with DC	Cable fails on first energisation	Project halted; delayed reinforcement; additional costs to move MVDC converters for use elsewhere as converters or STATCOMS.	1. Short time 27kV DC testing completed on the circuit with no problems. 2. All cables to be fully discharged over an extended period (at least 24 hours) before DC energisation.	**10**
1.06	Existing OHL integrity with DC	Suitability of existing OHL for DC operation	Flashovers across the insulators that provide structural support between the conductors and towers are likely to necessitate switching off the whole of the MVDC scheme for a period of time.	Perform study of OHL insulation requirements for designed DC voltage, visually inspect insulators on existing line and replace if necessary.	**9**
1.07	Practical realisation of capacity gain	Theoretical capacity gain with DC cannot be achieved.	Anticipated further deployments in the UK will be discouraged by less attractive business case.	Prior to decisions to proceed, pre-engineering studies will be carried out for the identified circuit to determine requirements for prudent operation and resulting anticipated capacity release	**2**

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
1. Technical risks					
1.08	Practical flexibility for replication of technology	Ambitious advancement of a combination of technologies from TRL in the region of 5 to TRL 7 cannot be achieved to facilitate project replications.	Anticipated further deployments in the UK will be discouraged by prohibitive cost to overcome unproven aspects.	Informal discussions have taken place with several potential vendors to understand the range of technology available for MVDC converters and constraints. A realistic functional specification has been developed in the proposal phase, and will be developed in the initial design phase to produce a detailed technical specification for the procurement process.	3

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
2. Procurement, manufacturing and installation risks					
2.01	Few suppliers of MVDC equipment	Limited number of tender returns from vendors for procurement of MVDC converters.	Receipt of uncompetitive tenders that are not in line with principles of good value for money for customers; decision to halt innovation project.	Informal discussions have taken place with several potential vendors and we are confident that we will receive several tender returns through the conventional competitive bid process. Efforts will continue to be made to ensure that the specification requirements are reasonable and realistic for commercial offerings to be received.	4
2.02	Size of equipment	Insufficient available space and/or site access for installation of large plant items	Significant loss of investment in large equipment that cannot be installed; delays to reinforcement.	Preliminary assessments indicate that access is possible for plant and space is available at both sites.	5
2.03	Cost of installation of AC system is significantly higher than estimated	Prohibitive cost of cable installation for AC system. These costs are site-specific and heavily dependent on excavation costs (in this case directional drilling costs), with a high variance.	High cost of crucial mitigation measure delays entire innovative demonstration project.	1. Perform thorough pre-engineering studies before defining the detailed cable route. 2. Pause the project if there is no space available on the bridge.	10

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
2. Procurement, manufacturing and installation risks					
2.04	Easements/ wayleaves	Inability to obtain a wayleave / easement for the parallel subsea AC standby circuit.	Lack of wayleave / easement for crucial mitigation measure delays entire innovative demonstration project.	Perform thorough pre-engineering studies before defining the detailed cable route and liaise closely with owners and planning authorities.	25
2.05	Cost of MVDC equipment	Prohibitive cost of MVDC equipment which is significantly higher than the estimated cost in proposal stage.	Project budget is not enough for delivery of the project objectives and project should be halted	1. Develop an optimum design for MVDC equipment and ensure unnecessary and expensive specifications will not be part of final specifications 2. Carry out competitive tendering process to ensure the best value for money	10
2.06	Damaged equipment	Equipment arrive on site are damaged due to improper packaging and shipment	Significant effect on delivery time and project programme	1- Ensure proper packaging and shipment with supplier 2- include appropriate penalties in terms and conditions to protect the project against damage or late delivery of the products	8
2.07a	Delay in procurement of Holistic Monitoring System	Requested supplier information for tender is not available for SoW	Delay in ITT invitation to suppliers with knock on delay affecting commissioning of monitoring equipment and missing SDRC deadline	Bring program forward so problems are identified early. Soften requirements to allow for supplier input at ITT stage and some development at the operational stage	12

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
2. Procurement, manufacturing and installation risks					
2.07b	Delay in commissioning of monitoring equipment	Holistic monitoring equipment is not in place before energisation of the MVDC link	The impact of conversion from AC to DC, the stress on the cables and possible damaged to the cable circuits cannot be monitored	1- Commissioning of the holistic monitoring system is planned to take place before commissioning of the MVDC link (at least 6 month earlier than originally planned) 2- Early IT engagement to ensure incorporating monitoring system in SP Energy Networks infrastructure comply with IT security requirements	6
2.08	Delay in delivery of converters	Delay in delivery of the MVDC equipment	The overall impact on timely delivery of the SDRCs and work in other work packages	1-Considering contingency time for production of the converters 2- Effective monitoring of the manufacturing process and define set dates for factory acceptance tests at time of contract 3- include appropriate penalties in terms and conditions to protect the project against damage or late delivery of the products	8
2.09	Most suitable MVDC supplier is not selected	Required Project/Supplier development work and MVDC - Link operation cannot be achieved	MVDC link is not fit for purpose, resulting in decision to halt innovation project and/or failure to meet several SDRC project outputs.	1) Invitation to tender sent out to all suppliers identified in 2 stages of PQQ. 2) 1st stage control strategy studies completed early to inform tender evaluation 3) Leading MVDC expert part of MVDC link tender evaluation panel. 4) Cardiff University system analysis available before signing off on contract.	6

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
2. Procurement, manufacturing and installation risks					
2.10	MVDC supplier carries out the project as a one-off for SPEN	As a large customer, the selected MVDC link supplier modifies a HVDC converter design to curry favour with SPEN, but has little interest in entering the MVDC market.	BaU benefits of MVDC cannot be realised, Angle-DC has little effect on the emergence of the MVDC market	1) Pursue MVDC supplier's intent during MVDC evaluation 1-2-1s, with appropriate lines of questioning. 2) Perform market research into supplier's other DC - link projects 3) Effectively disseminate learning from project to lower the bar to MVDC market entry and keep supplier interest	8
3. Operational risks					
3.01	Landowners	Opposition to the conversion of the AC cable to operate with DC.	Discontinued operation and loss of significant investment.	Engage carefully and thoroughly with landowners to explain the change of technology and safe operation of cables under DC.	4
3.02	Reliability of the scheme	Inadequate reliability and availability of MVDC converters	Operation of the link is compromised.	1. Efforts will continue to be made to ensure that the specification requirements are reasonable and realistic for commercial offerings. 2. An AC link between Anglesey and Bangor will be commissioned.	6
3.03	Maintenance requirements	Complex system installed that is impossible to maintain in reasonable timescales.	Likely interruptions of supply to customers; and increased costs for additional resources in maintenance teams.	Seek to work with the manufacturers to understand maintenance requirements and the impact on the design or selection of components; as well as on-going training and development of staff.	4

Risk No.	Issue	Risk Description	Potential Impact	Control & Contingency Measures	Overall Risk (2-40)
4. Project Management Risks					
4.01	Higher costs	Cost of scheme higher than anticipated	Exceedance of project budget; and risk of halting the demonstration project.	Engage carefully and thoroughly with landowners to explain the change of technology and safe operation of cables under DC.	20
4.02	Experience and HSE	Staff lack of experience and knowledge of new equipment	Inefficient working and errors.	1. Efforts will continue to be made to ensure that the specification requirements are reasonable and realistic for commercial offerings. 2. An AC link between Anglesey and Bangor will be commissioned.	6
4.03	Resources	Sufficient resources are not available in SP Energy Networks to deliver the project	Delay in delivery of the project and impact on quality of deliverables	Seek to work with the manufacturers to understand maintenance requirements and the impact on the design or selection of components; as well as on-going training and development of staff.	4

SECTION 11 OTHER

SECTION 12 ACCURACY ASSURANCE STATEMENT

The Project Manager and Director responsible for the 'NIC – Angle-DC Project' confirm they are satisfied that the processes and steps in place for the preparation of this Project Progress Report are sufficiently robust and that the information provided is accurate and complete.

Steps taken to ensure this are:-

- Regular update reports from each project team member for their area of responsibility.
- Evidence of work undertaken by the project team is verified by the section manager as part of their day-to-day activities. This includes;
  - Checking and agreeing project plans.
  - Holding regular team project meetings and setting/agreeing actions.
  - Conducting frequent one-to-one meeting and setting/agreeing actions.
  - Confirming project actions are completed.
  - Approving and signing off completed project documents.
  - Approving project expenditure.
- Weekly updates are received by each section manager of the progress of the work their department is undertaking.
- Director and Senior Management summary reports for the project progress are produced.

Signature (1): James Yu – Future Networks Manager

James Yu

Signature (2): Colin Taylor – Engineering Services Director

Colin F. Taylor