Final report

1.1 Project details

Project title	Offshore Cable Installation
Project identification (program abbrev. and file)	EUDP 12-I64012-0102
Name of the programme which has funded the project	Energistyrelsens udviklings- og demonstrations program
Project managing company/institution (name and address)	Siemens Wind Power A/S, Borupvej 16, 7330 Brande CVR NR: 76486212
Project partners	NKT Cables A/S, Toftegårdsvej 25, 4550 Asnæs CVR NR: 25711548
CVR (central business register)	76486212
Date for submission	22.03.2016

1.2 Short description of project objective and results

The objective has been to develop and demonstrate methods for cable installation, which via improved cable fabrication- and installation techniques can reduce costs for installation of array-, infield- and export cables in relation to Offshore Wind Turbines with 30 % compared to traditionally employed offshore cable- fabrication and cable installation-techniques.

The purpose has further been to provide for a more expedient cable installation process whilst at the same time reduce commodity risk exposure. The objective of the project has in addition been to design and produce a cable type – cable in pipe - which will allow for an improved power transmission rate.

The result of the project have provided for engineering of an alternative installation method whilst using a devil's advocate approach to the ideas fostered during the working process.
The concept developed is in short based on pre-installation of a PE pipe followed by installing the cable in the pipe.
Four test installations of various nature have been performed, and the concept has been promoted at various meetings and conferences.
For details of the test program and results etc. reference is made to appendices.
The concept will be introduced on the 2017 Nissum Bredning test project for array cables and cables to shore.

Danish version:

Formålet med dette projekt har været at udvikle og demonstrere metoder til kabelinstallation, der via effektiviseret kabel-fabrikation og kabel-installationsteknikker kan reducere omkostningerne til kabelinstallation mellem offshore møller i møllepark og export kabler til land med en omkostningsreduktion på 30 % med samtidig opnåelse af en hurtigere og sikrere installations proces, hvorved skadesomfanget på offshore kabler forventes reduceret signifikant. Formålet har desuden været at designe og producere et kabel der - alt andet lige - reducerer effekttabet i eltransmissionen.

Som resultat har projektet via en kritisk idegenerering givet udviklingen af et nyt kabel i rør design. Konceptet er bl.a. baseret på preinstallation af et PE rør efterfulgt af installation af kablet i PE røret.
Designet er konkret udviklet til en pre-prototype installation og ialt 4 forskellige installations tests er udført.
Konceptet er aktivt markedsført til konkrete projekter ved møder med relevante aktører samt omtalt på konferencer etc.
Detaljer er beskrevet i medsendte appendix og nedenfor er dette appendix ofte refereret incl reference til konkrete afsnit.
Konceptet vil blive introduceret på Nissum Bredning projektet der er planlagt til opførelse i 2017.

1.3 Executive summary

The purpose of this project has been to develop and validate alternative method(s) for fabrication and installation of offshore cables to enable a cost reduction of 30 % for installed cables whilst at the same time reduce the considerable hazard to the cable during installation as well as during the life cycle of the offshore wind farm.
The primary aim has been to focus on the fabrication and installation of array cables in offshore wind farms – cables between turbines, between turbines and transformer station - and via the below described test program to validate and document the suitability of alternative cable fabrication and installation techniques.
Based on the technological achievements and experiences gained under this project also export cables- cables from wind farms to shore - has been included as a relevant application area for the technique evolved under this project.

The goals for this project is :
- to reduce costs for cable manufacturing and installation with 30 % thus reducing respectively Capex and OPEX for developing, building and operating offshore wind farms with minimum 2.5 %.
- to reduce or eliminate subsea intervention by divers or ROV during installation
- to enable swift and fast power production upon turbine installation
- reduce cable hazard and deterioration and thereby reduce maintenance costs

The main technical achievements under this project have concluded to introduce a cable in pipe technology by which a PE pipe is preinstalled and succeeded by a cable in pipe installation.

The project has been performed in cooperation with the following important partners:
- NKT Cables (partner under the EUDP program)
- Plumettaz SA – Switzerland
- Wavin bv – Netherlands

In addition other companies and institutes have been approached with purpose to gain support and/or achieve a technical evaluation of details of the concept. Amongst such companies are
- DVN-GL
- DHI
- Installation companies such as JD Contractor and CT offshore
- Cable manufactors

In essence

NKT Cables have designed, engineered and supplied the cables for all tests

Plumettaz have for Siemens provided design and engineering for all the cable in pipe technology required for pushing and pulling the cable into and through the pipe – generally titled as WaTuCab.

Wavin bv have for Siemens engineered and provided all PE pipes used for the project.

The main activities under this project can be headlined as follows:
1) Desk studies throughout the cause of the project
2) Detailed design of cable in pipe construction, cable installation at wind turbine foundation and installation techniques and procedures
3) Full scale cable in pipe installation test onshore to test and document capability to install cables in PE pipes (test performed at Lindø)
4) Stop and go test performed at Kalundborg
5) Full scale cable installation test performed in Thyborøn harbour
6) Installation test on CS Sia
7) Impact testing at Wavin laboratories in Holland
8) Burial stability evaluation
9) DNV-GL concept evaluation
10) Introduction of the technique to projects such as the Westermeer Wind in Holland, the Aberdeen Bay wind farm project, Mejl Flak wind project and finally the Nissum Bredning project.
11) Market introduction
The goal for this project is:
- to reduce costs for cable manufacturing and installation with 30 % thus reducing respectively Capex and OPEX for developing, building and operating offshore wind farms with min. 2.5 %. The goal is further:
- to reduce or eliminate subsea intervention by divers or ROV during installation
- to enable swift and fast power production upon turbine installation
- reduce cable hazard and deterioration and thereby reduce maintenance costs

It is concluded that the project has been successful even though that the concept has not yet been introduced on a wind farm.
The main elements of the cable installation concept will however be introduced on the Nissum Bredning test project, which is scheduled for installation during 2017.

This final report (slutrapport) is relatively narrative. Quite comprehensive reporting and design works forms basis for this report. Detailed reports are addressed in the text below and almost all documentation is attached in the appendix. This includes a short video, illustrating important components of the work.

1.4 Project objectives

The objective has been to develop and demonstrate methods for offshore cable fabrication and installation, which via alternative techniques can reduce costs for installation of array-, infield- and export cables in relation to Offshore Wind Turbines with 30 % compared to traditionally employed offshore cable- fabrication and cable installation- techniques.
The purpose has further been to provide for a more expedient cable installation process whilst at the same time reduce risk exposure. The objective of the project has finally been to design and produce a cable type – cable in pipe - which will allow for an improved power transmission rate and thus if possible reduce losses due to e.g. cable armoring.
The result of the project have provided for engineering of an alternative cable in pipe installation method whilst using a devil's advocate approach to the ideas fostered.
The project is in great detail described in the attached Appendix. Most steps are addressed under the following headlines:

1) Desk studies throughout the cause of the project

2) Design of cable in pipe construction, cable installation at wind turbine foundation and installation techniques and procedures
3) Full scale cable in pipe installation test onshore to test and document capability to install cables in PE pipes (test performed at Lindø)
4) Stop and go test performed at Kalundborg
5) Full scale cable installation test performed in Thyborøn harbour
6) Installation test on turntable CS Sia
7) Impact testing at Wavin laboratories in Holland
8) Burial stability evaluation
9) DNV-GL concept approval
10) Introduction of the technique to projects such as the Wester Meer Wind in Holland, the Aberdeen Bay wind farm project, Mejl Flak wind project and finally the Nissum Bredning project.
11) Market introduction

The goal for this project has been:
- to reduce costs for cable manufacturing and installation with 30 % thus reducing respectively Capex and OPEX for developing, building and operating offshore wind farms with minimum 2.5 %.:
- to reduce or eliminate subsea intervention by divers or ROV during installation
- to enable swift and fast power production upon turbine installation
- reduce cable hazard and deterioration and thereby reduce maintenance costs

The concept developed is - in short - based on pre-installation of a PE pipe followed by installing the cable in the pipe.
Four test installations of various nature, have been performed, and the concept has been promoted at various meetings and conferences.
For details of the test program and results etc. reference is made to appendix attached - the appendix is often referred incl. actual and relevant pages.

1)Desk studies before and throughout the cause of the project.

An initial assessment of the offshore cable market, were made prior . Based on accessible cable information from various wind farms such as Anholt Wind Farm, LondonArray, Baltic One and others it became obvious that installation techniques and pricing were quite fluctuating and in certain cases it appeared that cable fabrication and installation were performed in an inexpedient way resulting in time consuming installations and in some few incidents cables were damaged as result of inexpedient coordination between cable installation operations and in some cases with other operations such as turbine installations.

It rapidly became evident that cable installation represents a disproportionate part of incidents related to wind farms and thereby insurance claims in relation to building and operation of wind farms.

It also became apparent, that armored offshore cables often represents a cost of approximately 3 times the cost for a terrestrial cable of similar capacity.

The reason for this is technical requirements for cable armoring and increased demands for water tightness etc. but also and not least a far less competitive market for fabrication of offshore cables.

Based on this preliminary market assessment a number of alternative installation methods were priced using traditional installation of armored cables as baseline. A total of 9 alternative installations were budgeted ref. app 1.2.2.

It appeared to the project group, that a cable in pipe installation scenario, were worth investigating further.

Using a critical approach, to the concept and the project group ideas, have naturally motivated an iterative process including additional desk studies and not least meetings with vari-

ous experts and companies. This includes DNV-GL which have performed a concept evaluation and approval of the installation concept

Ref. Appendix 1.2.1

2) Design of cable in pipe construction, cable installation at wind turbine foundation and installation techniques and procedures

The cable in pipe concept introduces a design which enables all installation work to be performed from topside only thus excluding use of divers or ROV's for subsea intervention.

The concept includes the following elements

- The cable design
- The cable in pipe structure
- Telescopic riser
- Bending restrictor acting as CPS (cable protection system) at the seabed

The concept offers the following advantages

- All work are performed from topside and from vessels – no subsea intervention required during installation
- The concept offers flexibility to accommodate for seabed erosion near the foundation

Three different cable designs have been introduced

- One single phase 630 mm2 72 kV cable solid alucore
- One three phase – 3 x 300 mm2 36 kV sector shaped solid cores alucable semiconducting jacket
- One three phase – 3 x 300 mm2 36 kV sector shaped solid cores alucable

NKT-cables have performed all cable design cable manufacturing and certification

Extensive concept and detailed design works are performed under this program. Installation procedures are also described.

Kindly access all detailed design works and installation procedures etc.i in Appendix

Ref. Appendix 1.2.3 , 2.1, 2.2, 2.3

3) Full scale cable in pipe installation test onshore to test and document capability to install cables in PE pipes (test performed at Lindø)

At an early point in the project contact were made to Plumettaz in Switzerland with purpose to investigate to opportunity to perform an installation based on preinstalling a PE pipe followed by installing the 3 phaze cable in the pipe by the WaTuCab method. The WaTuCab installation method is described in appendix.

The partners NKT and Siemens agreed with Plumettaz and Wavin to perform various cable in pipe installations on land at Lindø. The choice of Lindø was based on the availability of a very long and horizontal land strip.

The test is in its entirety described in Appendix

It was concluded that the cable in pipe installation could be a viable installation method for installation offshore for array cables and eventually in the longer perspective for export cables of 25 km or more.

As described in the appendix it is required that cable density is balanced and friction between pipe and cable are assessed prior to any installation.

Ref Appendix 1.1.1 and video app 1.3.1.

4) Stop and go test performed at Kalundborg

As a result of the always practiced critical approach it was worried and considered a risk as to whether a temporary cable in pipe installation stop were introduced could potentially prevent the installation to be continued later.

In other words it was worried whether the cable would eventually glue itself to the inner walls of the pipe.

As it appears from the report attached in App 1.1.2 the cable movements could easily without recordable difficulties be re-started after 5 days left in the pipe.

The conclusion was that the brine solution and the polywater used in the installation process performed no harm to the installation and no change in friction was registered.

Ref Appendix 1.1.2

5) Full scale cable installation test performed in Thyborøn harbour

A 700 meter installation test was performed in Thyborøn in 2013. The installation involved in principle all elements of a full scale installation inclusive fabrication and installation of telescopic risers and bending restrictors.

The test involved in total 7 repeated cable in pipe installations. The only installation element not introduced in the Thyborøn Harbour test was trenching of the pipe in the seabed.

The trenching operation was considered so much a separate installation element which had no consequence or implication on the main elements of the installation.

An important part of the test was the introduction of intelligent pigging after pipeinstallation but prior to cable installation. The potential advantages of such intelligent pigging, is considerable as it ultimately will substitute for the as built survey normally performed after the completed installation inclusive trenching. The reason for this is that the pipe-trajectory and thereby the cable-trajectory can be well defined relative to the seabed and thereby perform as documentation for burial depth in the seabed.

The test went successful and various companies were invited to witness the test amongst others Vattenfall.

Ref Appendix 1.1.1 and video 1.3.2

6) Installation test on turntable CS Sia

During the cause of the project we met from various sides some skepticism some of which was of political nature, some of which appeared based on individual business interests and considerations. Obviously the ultimate success of this entire project may significantly reduce the market for armored offshore cables.

As a consequence of the skepticism an idea was instigated to install the cable in pipe whilst the pipe were rolled on to a turntable followed by installing the cable in pipe offshore somewhat like a traditional offshore cable installation.

We agreed with CT Offshore to perform the installation on CS Sia in April 2015.

The installation served two purposes:

- To install as stated the cable in the pipe whilst drummed several times on a turntable for the purpose of enabling the installation as mentioned
- To install the cable in the pipe whilst drummed were considered somewhat an ultimate test for the WaTuCab installation method

The 700 meter cable installation in the PE pipe were performed successfully at a drum diameter of 4 meter

A separate report for this test can be assessed in App 1.1.3 and video 1.3.4

7) Impact testing at Wavin laboratories in Holland

Again as a result of a critical approach it was considered vital to evaluate the sustainability for the cable in pipe solution during installation and during a wind farm life time of at least 25 years.

It became relevant to consider impacts to the cable in pipe structure and compare artificial laboratory made impacts by similar so to armored cables.

It was agreed to perform such laboratory tests at the waving laboratories in Holland.

The conclusion from the test is that whilst certain impacts were detrimental to the armored cable the similar impact on the cable in pipe structure did not even touch the cable inside the pipe.

This test is further described in App 1.1.1, 2.1.1 and video 1.3.3

8) Burial stability evaluation

One of the topics which require a strong focus on the cable in pipe construction is the limited density of the total structure.

The total density may - depending on the actual cable and pipe dimension be in the order of only 1.2 to 1.4.

With the structure – cable in pipe - buried in soil conditions of a higher density e.g. 2.0 provides basis for a stability evaluation with purpose to form basis for safeguarding that any trenched light weight object e.g. cable in pipe shall not expose out of the seabed or even "move" in the seabed to a lower burial depth that required. Movements could theoretically be enforced by thermal expansion of the pipe.

Pipe and cable exposures are often caused by seabed erosion but such aspect is not included in this evaluation.

We have requested DHI to consider and evaluate this topic and there preliminary report is attached in the App

The very narrative conclusion is that either the weight of the structure must be increased by adding additional weight to the pipe or it must be ensured via analysis of the soil conditions that the grainsize distribution around the trenched pipe are suitable for "locking" the pipe in the seabed no matter eventual incremental radial expansions of the pipe as result of the applied heating as result of the power transmission in the cable.

Additional tests and the relevance hereof are at present discussed with DHI. Any further work will eventually be performed under a different scheme as this project is per definition terminated by 31.12.2015

Please find the DHI preliminary report attached in Apendix 1.4.

9) DNV-GL concept approval

In continuation of the concept development we decided to have a third party evaluation made on the concept with purpose to ensure that the work under this project could be considered on the right track.

Consequently we requested DNV-GL

- to consider the concept idea
- to evaluate all design works
- to evaluate testing performed and
- to organize a workshop with relevant experts

The workshop did clarify a number of issues and all questions were satisfactorily answered during the workshop

DNV-GL produced a summarizing report which is attached

Ref Appendix 1.5

10) Introduction of the technique to projects such as the Westermeer Wind in Holland, the Aberdeen Bay wind farm project, Mejl Flak wind project and finally the Nissum Bredning project.

Introduction is dealt with in the below sections of this report

11) Market introduction

Introduction is dealt with in the below sections of this report

1.5 Project results and dissemination of results

It can be reminded that the main motivator for the project has been

- to reduce cost for fabrication, installation (use of low cost vessels) and operation of offshore cables in relation to offshore wind farms.
- to reduce – if possible - power transmission losses in cables
- to enable an easier replacement of array cables in case of malfunction without re-trenching as the pipe will often be reused for installation of a new cable

all with the purpose to reduce levelized cost of energy for offshore produced wind power and therefore for Siemens Wind Power and ultimately Denmark to stay in the forefront with regards to savings and innovations.

The cable project has been a success in the sense that full scale tests have been performed and it has been proven that significant savings with regards to cable manufacturing and installations can be achieved. It is concluded that savings in cable production together with installation procedures requiring a less costly vessel contingency will provide opportunity for a saving of more than 30% to array cable installations.

The intention has been throughout the project to invent a cable design and cable installation procedure which as a result can contribute to a saving of levelized cost of offshore wind energy to a minimum of 3% of Capex and Opex.

The application phrased the following:

“”””””
This project implies introduction of
- a flexible riser for cable installation and protection
- a flexible J-tube
- pre-installation of a pipe from turbine foundation to turbine foundation
- pre-installation of cable on drum prior to offshore shipment
- introduction of a push-pull system for installation the cable in the preinstalled pipe whenever
suitable in the overall wind farm installation program
- low cost vessel for installation of pipe between turbines

The advantages will be
- ability to utilize non-armored cables
- installation will require low cost vessel for installation of polyethylene pipe
- trenching of pipe and cable will be less critical and can be performed independent of other operations
- installation will be far less weather sensitive
- cable will be exposed to less risk of damage during installation.

The innovation process involves desk study, practical onshore demonstrations, full scale tests of parts
and installation procedure in harbor or other protected environment.
“”””””

It is suggested that all targets as per the latest agreed milestone plan has been met and complied with, with the exception that further detailed planning and detailed project specific design for the Nissum Bredning project will be conducted under a different scheme under the Nissum Bredning Test Project.

Dissemination of project results have been done in relation to actual projects such as Westermeer wind in Holland, Mejl Flak at Århus and Nissum Bredning, to companies such as Energinet DK, SEAS, DONG and Vattenfal.

The concept have further been promoted at conferences such as cable conference in Bremen in April 2015 and at JI-Cable in Paris in June 2015.

Conference presentation Appendix 1.7 and video 1.3.5

1.6 Utilization of project results

For Siemens Wind Power offshore cabling is part of Balance of Plant and only a direct part of the business when Siemens are responsible for turnkey projects. The primary motivation for Siemens is to motivate cost reductions for offshore wind power. As the manufacturing of wind turbines represents less than 50 % of the total cost of a wind farm cost savings in Balance of Plant elements must be achieved.

Patent have been taken out for the riser concept by Siemens. The project partner NKT- Cables are entitled to use the concept free of charge up to and inclusive 2025.

It is expected that the cable installation in Nissum Bredning project – under which the cable in pipe concept is intended used - will motivate other turnkey projects to introduce the same concept for the obvious reason to cut costs, reduce loss of power and enable an easy change out of cable in case of malfunction.

As stated above the concept has met some scepticism during the evolving process, most of which have been technically and economically unjustified.

It is anyway expected that as soon the concept will achieve foot hole in a project the potential cost saving will motivate further introduction in the offshore wind farm market

1.7 Project conclusion and perspective

The conclusion of the project is that the alternative cable installation concept proposed and tested is sufficiently validated for introduction to the cable design on a wind farm.

As addressed above, the alternative cable installation concept will - as local conditions may dictate - be fully or partly introduced to the Nissum Bredning project scheduled for 2017.

The reduced power losses in the unarmoured cable in pipe structure should also motivate introduction of the concept.

It is expected that the actual introduction of the concept to the Nissum Bredning wind farm will motivate and market the concept for other wind farms as well. The greatest hurdle considered is to overcome traditional and political barriers for the introduction.

The commercial perspective is that this cable in pipe concept increases the number of potential cable suppliers to include those cable manufacturers who traditionally only produces terrestrial cables. As a consequence the cable market for offshore wind farms is expected to become far more competitive.

It is suggested that the cable in pipe concept may later be validated for export cables to a length of 25 km or more.

21.03.2016

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