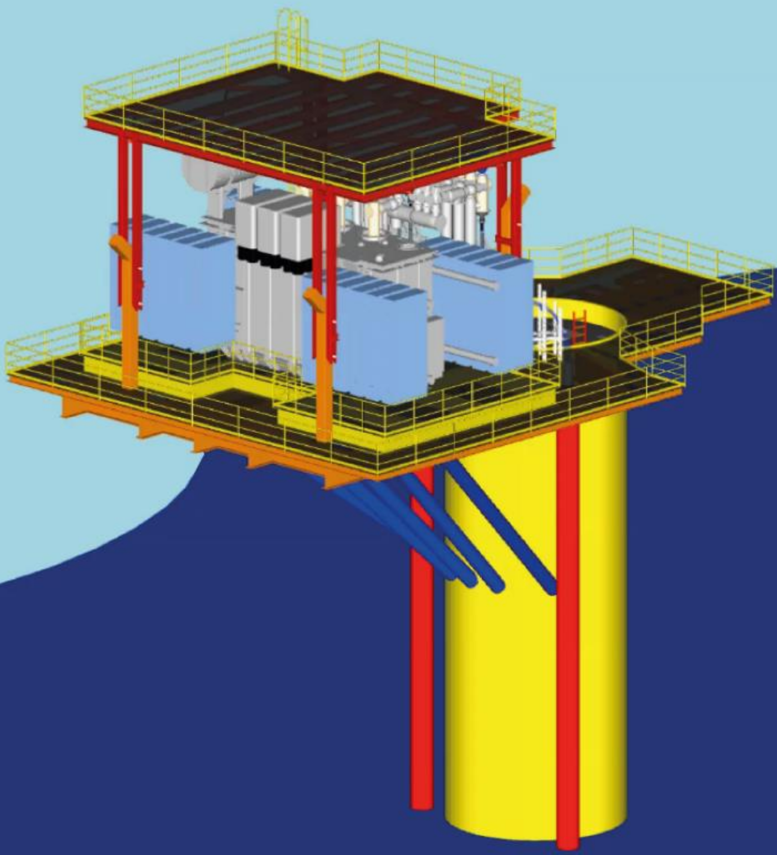
# HVAC Booster Concept

Final report – Journal 64015-0042

June 2017



## Funding programme

EUDP

## Partners

SIEMENS Gamesa RENEWABLE ENERGY

ALL NRG

ØGLÆND SYSTEM

# Content

## Project details

| | |
|---|---|
| **Project title** | HVAC Booster Concept |
| **Name of the programme which has funded the project** | EUDP |
| **Project managing company/institution** | Siemens Wind Power A/S,<br>Borupvej 16, 7330 Brande, Denmark |
| **Project partners** | Siemens Gamesa Renewable Energy<br>(former Siemens Wind Power)<br>AllNRG (former ALLNRG Enterprise)<br>Øglænd System |
| **CVR** | 76486212 |

## Short description of project objective and results

The project objective was to develop and demonstrate a new concept that substitute the traditional wind farm substation with smaller, cost reducing HVAC Booster Platforms mounted directly o turbine foundations. The project results showed great potential for installation of such a concept and test results showed that the concept could work in practice with the right tools. The project results and support from EUDP allows for the next level development of the concept, as the HVAC Booster Module still needs further development for market entry. This project was the first step towards an important part of Siemens' wind power cost reduction strategy.

**Danish version**
Formålet med projektet var at udvikle og demonstrere et nyt koncept, der kan erstatte den traditionelle transformerstation til vindmølleparker med en mindre, kostreducerende HVAC Booster platform, direkte på vindmøllens fundament. Projektets resultater viste stort potentiale for installation a konceptet og testresultaterne viste at konceptet kunne fungere i praksis med de rette redskaber. Projektet og støtte fra EUDP muliggør næste fase af udviklingen, da HVAC Booster modulet stadig har brug for udvikling før indtræden på markedet. Projektet var første skridt på vejen til en vigtig del af Siemens' strategi for kostreduktion af vindenergi.

## Executive summary

Wind farm substations constitute a relatively high share of the CAPEX for offshore wind projects. If the price of wind energy is to decrease, all parts of the wind farm have to lower both CAPEX and OPEX. This project aims at developing, designing and demonstrating a technology that will reduce both CAPEX and OPEX, and furthermore increase energy production safety.

Through three main work packages (WP) (design of guiding system, cable handling and tests), the project results show that it is possible to install one HVAC Booster Platform for every 60 MW turbines instead of one traditional substation. A concept study was conducted in the first WP, where recommendations concerned guiding bumpers and guiding cones to ensure a precise installation and recommendations on the switchgear connection. Further development by Siemens resulted in a concept design that was suitable for testing. The test results show that installation of the booster is actually possible and very likely to work in practice.

The project results allow for the level development of the concept, as the HVAC Booster Module still need development for market entry. All partners and stakeholders see great potential for the concept and benefits for the industry. However, the high voltage branch is quite conservative and it may take some convincing.

## Project objectives

Siemens Wind Power is in the process of developing a novel HVAC booster turbine concept. It is part of Siemens' cost reduction strategy in order to bring down the total cost by 40% for an entire offshore wind farm.
The costs of installing an offshore booster turbine station including cable handling represent typically 10-15 % of the total costs of deploying an offshore wind park. Therefore, lowering these costs is one of the key elements to lower the total Levelized Costs of Energy (LCoE). The objective of this project is to design a new guiding system for installation of HVAC booster stations and a cable-handling concept that will make offshore wind parks more cost-efficient.

To reach the target value for cost reduction, Siemens is in the process of developing a new HVAC Booster Concept for offshore wind turbines. This project does not concern the HVAC itself, but the plug-and-play cable handling system and guiding system for easier installation of the HVAC.

The project was divided into three main work packages with specific sub-goals and development and optimization of several important tools for cable handling and preparation:

- Designing the guiding system for installing HVAC Booster Station
- Cable handling concept: plug-and-play concept.
- Practical tests of the concepts (mock-up)

The project activities were aligned with the project milestone and activities from the application and the project reached all the given milestones.

In the matrix underneath, conclusions of each milestone are listed.

| | |
|---|---|
| **M1** | **Project delivery of final design of guiding system and final design and prototype of plug-and-play cable handling system.**<br><br>Concept and design of the cable handling system was developed and optimized during the two first months of the project with regular group meetings. Delivery of the prototype mock-up was due in the last part of the project and went according to schedule. |
| **M2** | **Concept reporting.**<br><br>The concept was reported and approved by the project group during the first months of the project. Only small and insignificant changes occurred. |
| **M3** | **Detailed design.**<br><br>For the detailed design, Rambøll was hired for external project delivery. Several proposals were developed and optimized for the final report. |
| **M4** | **DNV-GL concept approval.** |
| **M5** | **Final report guiding system.**<br><br>In November 2016, the final report for the guiding system was received. Se appendix. |

| | |
|---|---|
| **M6** | **Design 1. Draft.**<br><br>The first draft for the design has been carried out in cooperation with Siemens, AllNRG and Øglænd during our first meetings. Based on this "brain storming" the first design draft has been made. The first draft has been presented during meetings and optimizations have been made. |
| **M7** | **Static calculations done.**<br><br>Based on the optimized design static calculations of the design have been made and the design has been adjusted again. |
| **M8** | **Final design approved by Siemens.**<br><br>The final design has been presented at meetings with Siemens and AllNRG, and approved by the two parties. |
| **M9** | **Hardware delivered on site.**<br><br>Based on the design, hardware was cut in the right length and delivered to the premises of AllNRG for testing. Øglænd technicians have, in cooperation with AllNRG, assembled the test stand. Changes of the test stand have been made during the first tests. A part of the Booster has been redesigned due to weaknesses in the design and new tests were performed. |
| **M10** | **Working procedure described and approved.**<br><br>A working procedure has been made according to the functions of the Booster test stand describing functions and working procedures and functions. |
| **M11** | **DNV-GL concept approval.**<br><br>During the final testing of the Booster stand DNV-GL has been present for approval of the test stand |
| **M12** | **Design requirements for transformer skid/input for drawings and design calculations finalized.**<br><br>Design requirements were realized in cooperation with Siemens.<br><br>Due to the limited bending radius of the export cable, intensive discussions took place with regards to moving the cable hang off below the grating of the TP.. This is something to take into account when planning the cable route. At this mock-up, the bending radius was taken to its limit! |
| **M13** | **Planning and mobilization of test set-up on site finalized**<br><br>The time schedule for the practical mock-up was quite compressed. It would have been beneficial with more time for the practical works.<br>For future mock-ups, we need to plan outside the holiday season July/August. |
| **M14** | **Execution of practical work finalized.**<br><br>The execution went well, but due to holiday at suppliers, we needed to find other suppliers e.g. the scaffold supplier was not able to perform the works in time. |
| **M15** | **Reporting and video documentation.**<br>Throughout the project, we held meetings in the project group and sorted out any problems along the way. Photo documentation was send to Siemens.<br>Video documentation was not carried out, decision from meeting in the project group. |
| **CM1** | **DNV-GL concept evaluation**<br>Letter of evaluation was received after the mock-up demonstration. |

# Project results and dissemination of results

## WP1 – Project management

Prior to the project start, it was agreed upon that the project management should be divided between Siemens as technical project manager and Offshoreenergy.dk as administrative project manager. Siemens had the responsibility of ensuring progress and development of the cooperation between the project partner and alignment with the stated activities and milestones. Offshoreenergy.dk had the responsibility of the project economy, reporting and contact with EUDP. Through the project period, this division resulted in a good flow of tasks and following the project timeline for the technical WPs. Due to DNV-GL concept approval, the project was delayed 3 months in the end. Otherwise, the project progressed as planned and without unexpected challenges.

## WP2 – Design of guiding system

In this work package, the goal was to design the guiding system on a higher level than prior to the project. Prior to the project application, Rambøll made a concept study report for the HVAC Booster Turbine that included concept description, handmade drafts, cable pulling overview and 3D modelling. For WP2, Rambøll was again hired for the detailed design that additionally included installation bumpers and guides, guide cones below bottom frame, wind pressure and deflection of installation guides. Several proposals were submitted, revised and finally approved by Siemens.

Deliveries in this WP was

- Concept reporting (appendix 1)
- Detailed design (appendix 2)
- DNV-GL concept approval
- Final report guiding system (appendix 3)

**Conclusions**

The assessments made by Rambøll included calculations on

- Installation bumpers and guides
- Guiding cones below bottom frame
- Wind pressure on transformer unit at wind speed 14 m/sec.
- Deflection of installation guides and calculation of max. installation speed
- Bottom frame/drip tray below transformer unit
- Dropped object protection deck above transformer, cooler banks and GIS parts.

The guiding system must be designed in such a way that the transformer skid can be located on the offshore platform within tolerances of +/- 5 mm. Hence, several precautions must be made to obtain the precision. In each corner of the installation areal, vertical guiding bumpers must be installed with the so-called "cow horns" in the top for gross correction. Furthermore, to ensure precision of +/- 5 mm, fine tuning guide cones must be installed on the bottom of transformer module.

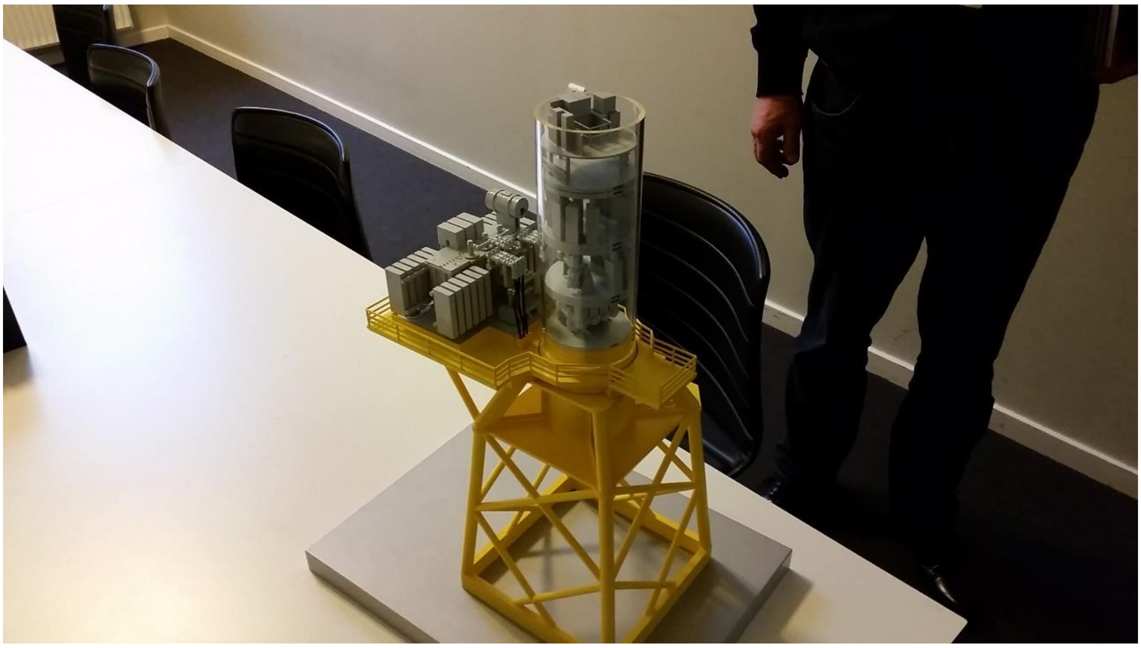


*Figure 1 3D production of full HVAC Booster concept for visualisation.*

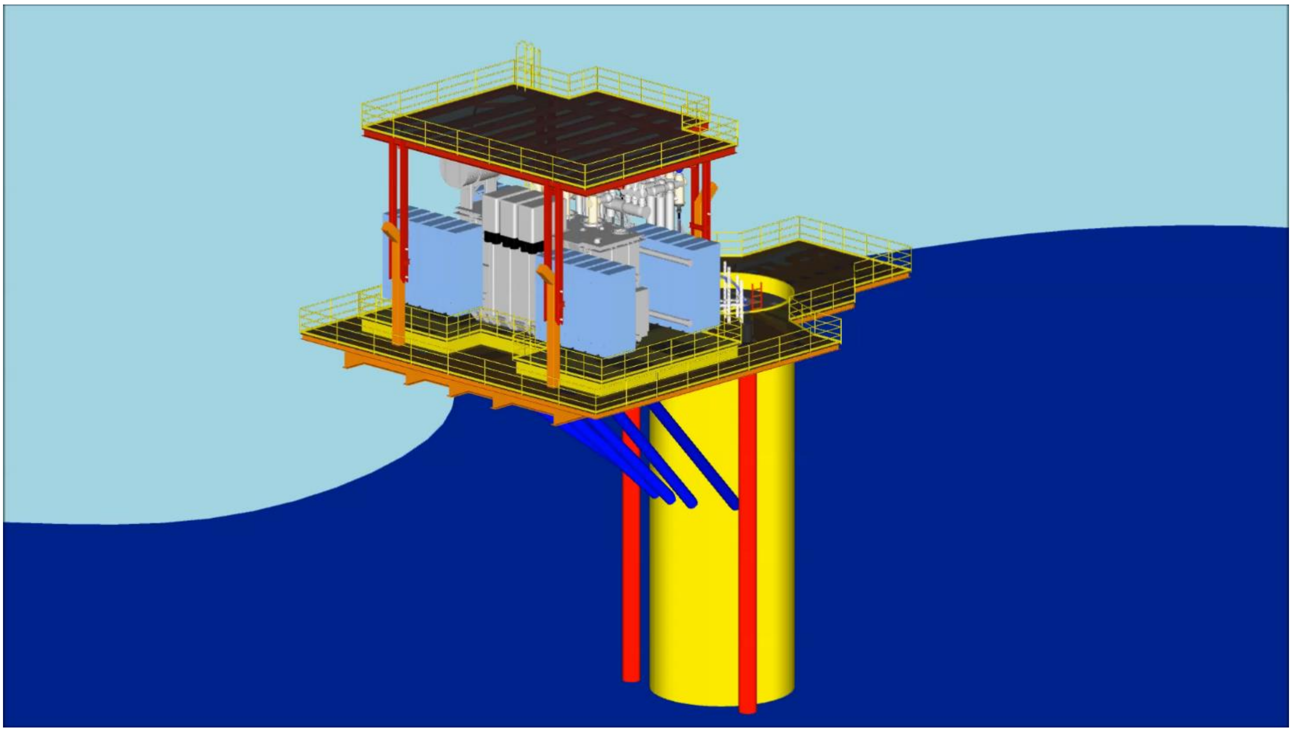


*Figure 2 Rambøll sketch of the full concept with the additional protection deck*

## WP3 – Design and development of cable handling

The purpose of this WP was to determine design and requirements on the cable handling system from the connection to the HVAC Booster Module to the array cable. First, the system should be designed in such a way that the module is easy to install (plug-and-play) and second, the working procedure and cable handling should be formulated for offshore conditions. The plug-and-play solution for the HVAC Booster Module was an important part of the concept, as it showed great installation cost reduction potential and possibility to be installed with a jack-up vessel.

Based on the study, the most promising solution was splitting the main array cable into three separate lines for connection. These lines are then bend in an upward, vertical direction on the booster platform. The line is fixed to a precise location according to the design of the HVAC Booster Module and equipped with end-fittings for better guiding and conductivity.

Deliveries in this WP were

- Draft design (appendix 4)
- Static calculations
- Hardware delivery
- Working procedure (appendix 5 and 6)
- DNV-GL concept approval (appendix 7)

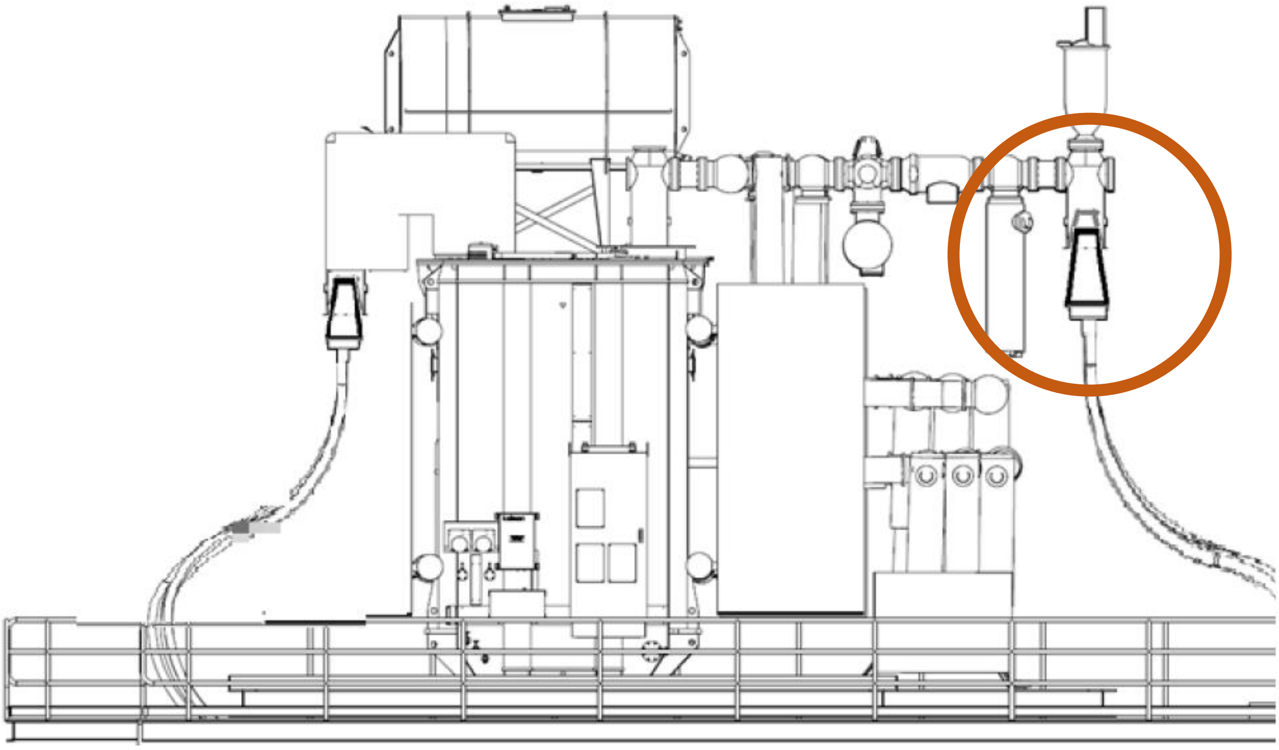


*Figure 3 Sketch of the connection between the HVAC Booster Module and the cable*

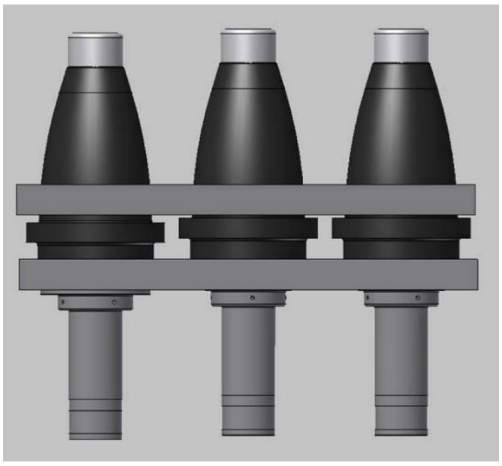


*Figure 4 The three connecting end fittings of the cable*

## WP4 – Tests

Final stage of the project was to demonstrate the concept for connection between the HVAC Booster Module and the array cable. Based on the findings in the prior WPs, the mock-up was build and demonstrated with involvement from all the partners and observed by DNV-GL and wind farm operators DONG Energy and Vattenfall.

Deliveries in this WP were

- Design requirements for transformer skid
- Planning and mobilisation of test setup on site (appendix 8)
- Execution of practical work

## Preparations before the demonstration

To reach the goal of concept demonstration, more than just a mock-up installation was necessary. First, the intended array cable consisted of three smaller cables, that all had to be connected separately for optimal conductivity. To expose the array cable, a cable stripper was developed during the project. Using electric driven idles and saw blades, the cable stripper was able to cut open the outer shell of the array cable without damaging the inner cables. The first version of the cable stripper was used in the mock-up test, but due to DNV-GL risk assessment, covers had to be installed to reach concept approval.

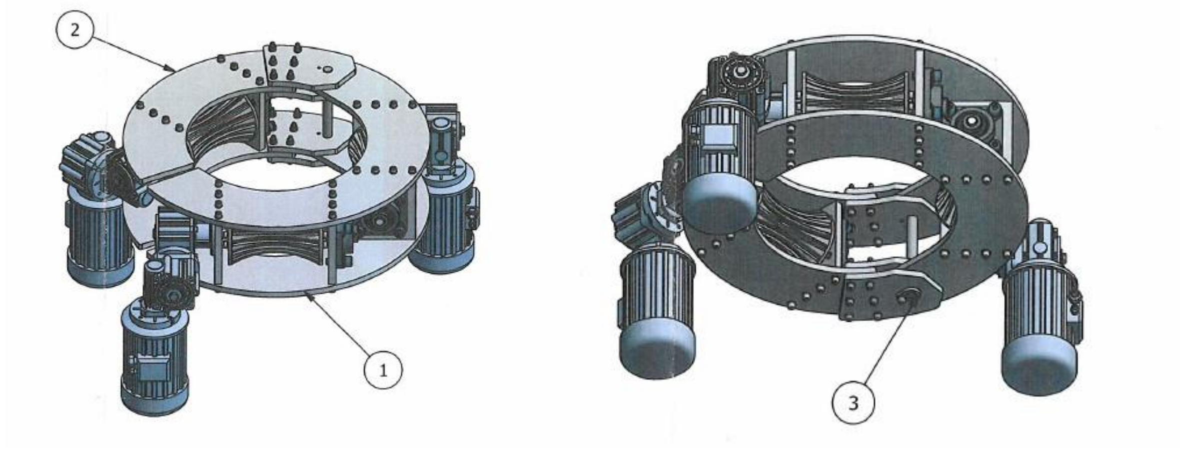



*Figure 5 Sketch of the center frame of the cable stripper machine*

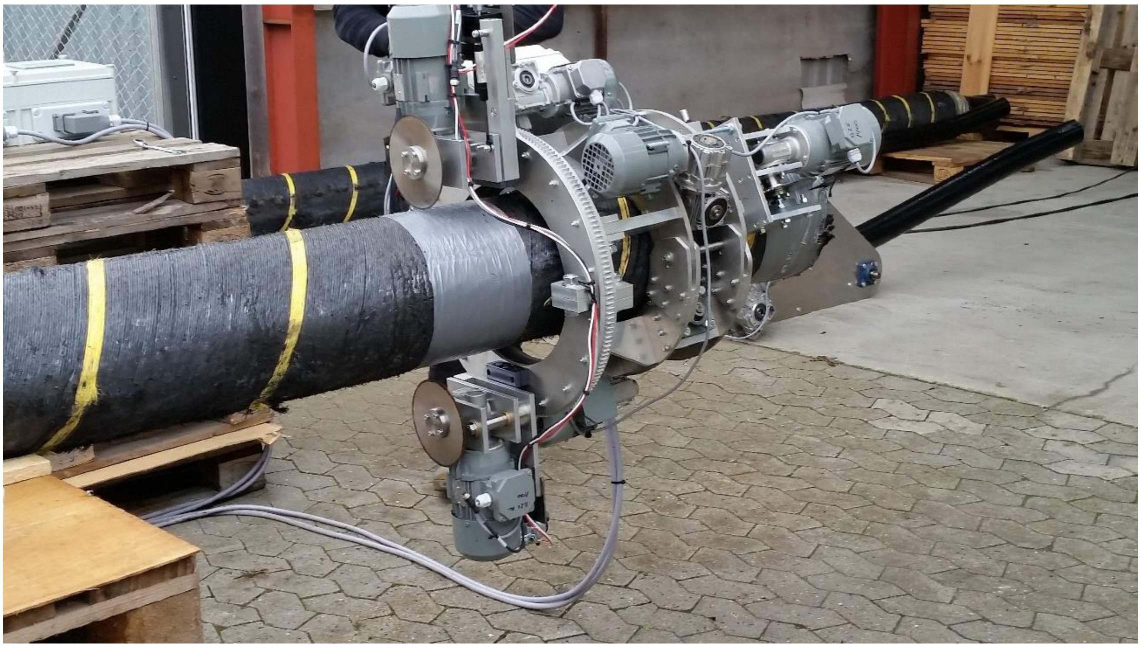


*Figure 6 As the array cable consists of three smaller cables, it was necessary to remove the outer shell and expose the smaller cables for connection. This cable stripper was developed during the project.*

Furthermore, due to cable thickness, a cable bender was developed to shape the cable for installation. To reach the right bending of the cable, the bender was designed in a triangular shape with two wheels in the bottom and an additional wheel in the top, which was equipped with an adjustment clamp. On the side of the bender, an electric motor was installed to pull through the cable.

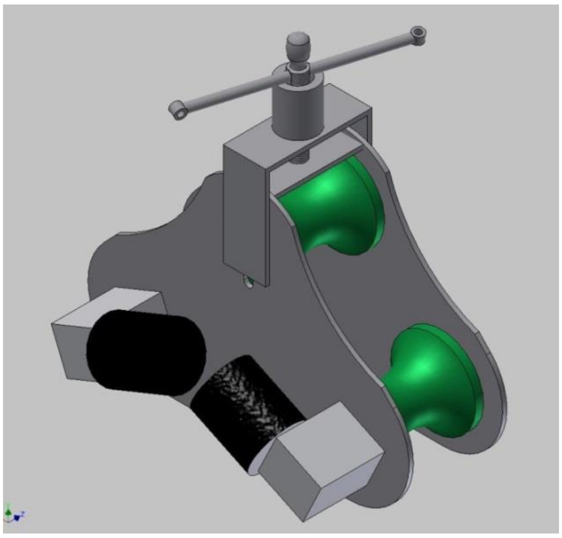


*Figure 7 Sketch of the cable bender*

*Figure 8 The produced cable bender*

Both the cable stripper and the cable bender were developed in cooperation with a local engineering company and further developed and perfected by Siemens' own engineers.

## Mock-up preparations

As the mock-up had a considerable size, a large outside storage space was cleared and prepared as tests site. First, steel plates were spread out as ground protection. Second, containers were installed to resemble real installation conditions and mounted up to 3-level high.


*Figure 9 Full mock-up setup build from containers, scaffolds and Øglænd profiles.*

From the ground level, the array cable was bend in a vertical direction and pulled through a pipe to the first level. From here, the cable was bend in two specific curves to imitate the installation situation offshore. To make the mock-up as realistic as possible, the cable had to be fastened to a specially designed support frame designed by Øglænd (appendix 8).

*Figure 10 Cable entry in the bottom of the mock-up.*

At the upper vertical part of the mock-up, the cables were fastened to the mechanical slideway that would slide the cables in an upwards direction and finally into the conductor bells.

*Figure 11 Cable connection with the HVAC Booster module.*

As the cables were not prepared for connection at arrival, special tools were needed for preparation. A special peeling knife was delivered by NKT to cut the outer shell on each separate cable and expose the conductor. To demonstrate a real offshore installation situation in WP4, the connecting part of the cable was further prepared with a guiding connecting cap.

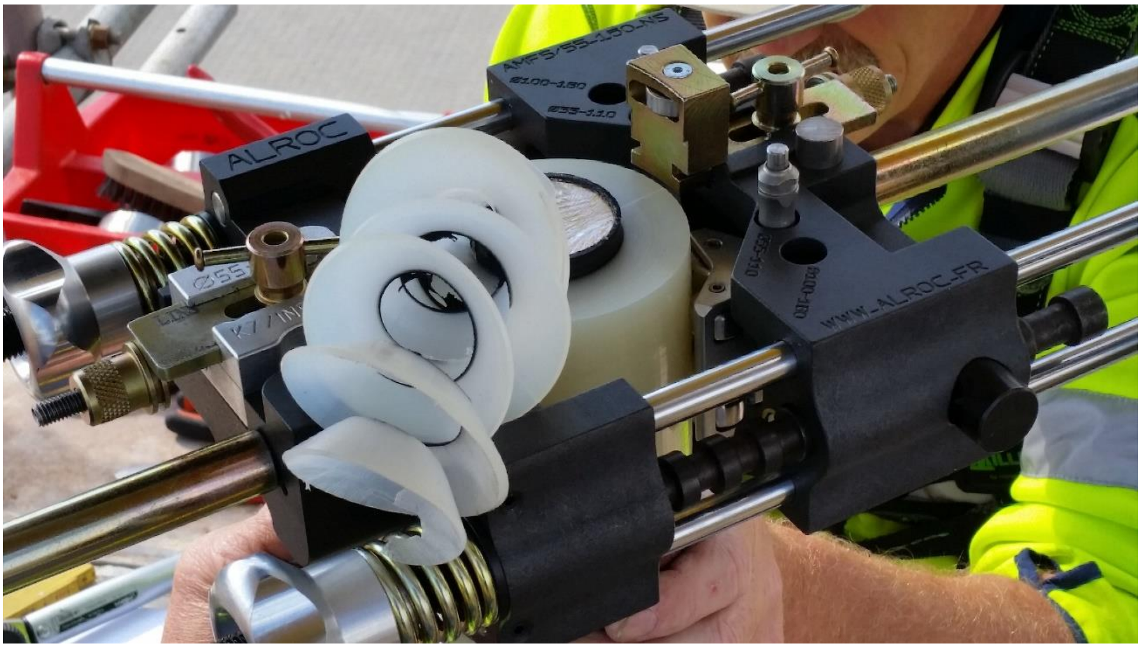



*Figure 12 Cable peeler for cable connection preparation.*

## Results of the demonstration

Generally, the results in WP4 were very good. It was the general opinion that the demonstration and construction of the mock-up and preparation of the cable went above expectations.

The cable stripper and bender were quite crucial to success and the construction and demonstration of these tools went very well. However, improvements can be made to both units. For example, the cable stripper had to be fitted with protective covers for DNV-GL approval. After the first test, the design was adjusted to fit the purpose. Before the final design fulfilled the expectations of both Siemens, ALLNRG and Øglænd, further tests were conducted.

As an important part of the HVAC Booster Module development, this demonstration showed that the connection concept is likely to work in a real installation situation and that it is possible to terminate three conductors at once. Preparing the array cable would in this case require conditions, where the cable stripper and bender could function, as cable preparation could only happen on-site.

The connection test showed that the guiding end fittings were suitable for connection, but lowering and placement of the HVAC Booster Module should be quite precise. This was also concluded in the guiding system report from Rambøll, that recommend both primary and secondary guide bumpers and additionally fine-tuning guiding cones in the bottom frame.

## Results in general

The objectives in the project were to

- design the guiding system for installing HVAC Booster Station,
- develop a cable-handling concept: plug-and-play concept, and
- conduct practical tests of the concepts (mock-up).

In the three separate WPs, these objectives were met with satisfaction from the project group. The guiding system was designed in cooperation with Rambøll that stated clear recommendations for the module design and installation requirements. Developing the cable handling system resulted in development and production of two necessary tools: the cable stripper and cable bender, which both performed purposefully. Furthermore, the concept study resulted in a solution that is able to connect three conductors at once. Together with the well performed mock-up demonstration, the project objectives were successful.

Concerning the project proposal, the project has investigated and developed a new design of the precision guiding system for installation of the booster platform at the same time, as the crucial issue of precision is not compromised. In line with Siemens' cost reduction strategy, the project has shown a significant leap towards a concept, where connecting the booster stations to the turbines and grid is cheaper and not customised to each case of installation.

## Commercial results

As part of the business case for the concept, Siemens expects a CAPEX cost reduction of DKK 300 mill. per 400 MW installed offshore wind farm. Øglænd expects the economic benefit from the project to be DKK 5 mill. in annual turnover in 2018 and VB Enterprise estimates a rise in turnover of approximately EUR 1 mill. until 2020.

During the project and since the project end, the partners have not yet seen any results in turnover, employment or export. The HVAC Booster Module still has to be further developed before it is ready for market entry. The part of the concept that was tested in this project constitutes one of the most important parts of the development. With the expected increase of 60 GW offshore wind power during the next decade and continuously cost reduction targets, there is a great potential for the HVAC Booster concept. The partners expect that some of the developers will implement this into their de-sign in the future and that a more comprehensive presentation of the results and concept will trigger industry interest.

## Dissemination

As most of the research and development in this project has been confidential and hence limited to the project group, public dissemination has been scarce. During the project period, Offshoreenergy.dk has disseminated the project through their newsletter, news feed and a press release (appendix 11). Furthermore, a video has been produced for the purpose of dissemination. It is in the process of approval, but the latest version can be found here.

During the project and after project end, the partners have been in contact with a few interested operators based on their visit at the test site. Several meetings have been held and further will follow as soon as the presentation material is ready. AllNRG has held potential costumer meetings and announced news about the project internally.

## Utilization of project results

The results obtained in the project were an important part of the development. The results showed, that the concept could work in practice and it has a great potential for further development. The successful design and demonstration allowed the HVAC Booster concept to enter the next level of development, where the entire concept is optimized and validated for market use. In this sense, Siemens expects to utilize the results commercially as a part of the development plan and ultimately a sales-ready product. As reducing the cost of wind energy, LCoE reductions are a part of Siemens' strategy. Now that the HVAC Booster Concept is closer to market entry, the strategy has been updated, now including one HVAC Booster Platform pr. 60 MW turbines instead of the traditional substation.

VB has an engineering department which advices and develops projects together with the project owner. Here they can use the results from the booster mock-up. If the concept is used in any project description, they anticipate that they will have a good chance of winning the contract for the actual work and this will result in a larger turnover. VB's business plan has not been updated, but the sales department has focus on this extra product / in-house competence.

Øglænd expects to commercialize the booster concept by doing presentations at major operators in a close cooperation with Siemens and VB. When presentation material is available, meetings with the potential customers are set up. They expect, depending on the turbine size, that 3 boosters can replace one conventional substation. A part of the concept of the booster might be used at the switchgear in transition pieces. Design adjustments are needed to fit for purpose.
The market potential is expected to be high as the booster will replace the traditional substations. By using the Booster Concept, the operators are contributing to Levelized Cost of Energy (LCOE) making offshore wind more competitive. No competition is seen in the market at the time being. Siemens, VB and Øglænd are first movers.

Siemens has patented the concept in Europe and is about to patent it in the USA as well. VB and Øglænd have not taken a patent in the process.

**Realising energy policy objectives**

In itself, the HVAC Booster constitutes an important part of the cost reduction plan presented by Siemens. With the new concept, it is compact, cost effective and faster to install. Additional, only a slight modification of the wind turbine foundation is necessary to install the booster module. All the listed benefits reduce wind project price and ultimately LCoE.

## Project conclusion and perspective

State the conclusions made in the project. Try to put into perspective how the project results may influence future development.

Wind farm substations constitute a relatively high share of the CAPEX for offshore wind projects. If the price of wind energy is to decrease, all parts of the wind farm have to lower both CAPEX and OPEX. This project aim at developing, designing and demonstrate a technology that will reduce both CAPEX and OPEX and furthermore increase energy production safety.

The project results showed that it is possible to install one HVAC Booster Platform for every 60 MW turbines instead of one traditional substation. A concept study was conducted in the first WP, where recommendations concerned guiding bumpers and guiding cones to ensure a precise installation and recommendations on the switchgear connection. Further development by Siemens resulted in a concept design that was suitable for testing. The test results showed that installation of the booster is actually possible and very likely to work in practise.

The project results allow for the level development of the concept, as the HVAC Booster Module still needs further development for market entry. All partners and stakeholders see great potential for the concept and benefits for the industry. However, the high voltage branch is quite conservative and it may take some convincing.

This project was the first step towards an important part of the cost reduction strategy

## Annex

1. Siemens Concept Reporting
2. Detailed design
3. Siemens Final Report Guiding System
4. Siemens Concept Drafts
5. Øglænd Working Procedure
6. Øglænd Fitting Instruction
7. DNV-GL Report
8. Øglænd Design of System
9. Press Release