Award #122: Deliverable 4.2 Final Report

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The New York State Energy Research and Development Authority ("NYSERDA") and the National Offshore Wind Research and Development Consortium ("NOWRDC") have not reviewed the information contained herein, and the opinions expressed in this report do not necessarily reflect those of NYSERDA, the State of New York or NOWRDC.

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Notice

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Acronyms and Abbreviations

AEP	Asset Earning Power
APS	Automatic Positioning System
ft	feet
FMEA	Failure Mode and Effects Analysis
GE	General Electric
JUV	jack-up vessel
kWh	kilowatt hours
m	meters
m/s	meters per second
MW	megawatts
NOWRDC	National Offshore Wind Research and Development Consortium
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
SBI	single blade installation
TRIR	total recordable incident rate

1 Project Report

1.1 Background

Most offshore blade maneuvers are single blade operations using a single blade installation (SBI) tool. SBI tools are controlled using four winches mounted on the jack-up vessel (JUV) crane. Frequently, these winches are mounted during the mobilization of the JUV for each operation. For offshore blade, main bearing, and pitch bearing repairs, the same equipment needs to be mobilized as for installations. Figure 1 in Appendix A shows an example of this equipment.

There are three areas of improvement with the use of the tagline system for offshore repairs: safety, time, and cost.

Safety presents several areas for improvement. The horizontal taglines that are currently used, can only pull in one direction, towards the crane. Because of this before each blade maneuver the JUV is positioned so the wind aero loading is pushing the blade away from the crane. However, if during the blade maneuver the wind shifts from the ideal position the effectiveness of the taglines is decreased. The next issue is that the installation of the taglines is complex and labor intensive with significant dangers involved.

The next area for improvement is time. The current tagline system takes two to three additional days to mobilize and demobilize for each repair operation. Reducing this time will enable faster responses to maintenance issues.

The third category for improvement is cost. Mobilization and demobilization efforts of the taglines currently must take place on the JUV. If these efforts can be completed off vessel, the rental time of the JUV can be reduced.

1.2 Project Details

The Automatic Positioning System (APS) eliminates horizontal taglines from blade lifting procedures. The system consists of two fans mounted on either side of the SBI tool. Each fan produces thrust that can be modulated to counteract environmental wind forces acting on the blade. This allows the blade to be stabilized and positioned during blade installation or removal activities. Pictures of the design are confidential. Figure 2 of Appendix A shows a diagram that illustrates this functionality of the APS.

The project team was composed of three companies. GE Renewable Energy is the prime recipient and project lead of the award. GE Renewable Energy is a wind turbine OEM and Service Provider with experience doing SBI installations both offshore and onshore. HVSA is a vendor and the APS developer. They are experts in creating lifting solutions for the wind and offshore industry. CREADIS is another vendor, with expertise in aerodynamic and aeroelastic analysis.

This project was executed in two phases. Due to the cost and limitations associated with an offshore wind turbine installation setting the decision was made to first develop an APS prototype to be tested at an onshore location. In the first phase of this project an onshore scaled prototype was designed, manufactured, and tested to learn about the APS's performance and safety systems. The learnings were then used to inform the conceptual offshore design development of the second phase.

During the first phase of this project GE and HVSA worked together to develop a prototype to be used with the onshore 68.7 meter blade SBI tool. At this point in the project design requirements were established, design and process FMEAs created and EHS and Product Safety evaluations completed.

Also, during this phase an analysis model of the SBI tool, blade, and APS substructures was created by CREADIS. This model was used to simulate the capability of the APS system. For this analysis the multibody simulation software SIMPACK was used. The simulation consisted of six substructures: the crane interface, SBI tool, blade, environmental wind field, blade aerodynamics and the APS tool. Details of this modeling process are confidential. Figure 3 in Appendix A shows a breakdown of the model subsystems. The crane interface, the SBI tool and blade are modeled as rigid bodies with mass, center of gravity and inertias applied. The substructures are constrained together and are allowed rotational degrees of freedom. The environmental wind field simulates different wind fields from the same input parameters. Input parameters include the mean wind speed, mean wind direction, mean up flow angle and turbulent intensity. Analysis details are confidential, and an example graph of a generated wind field is shown in Figure 4 in Appendix A. The blade aerodynamic model calculates the aero loads applied to the blade for various environmental conditions. To do this the blade is subdivided into "blade elements" where aerodynamic properties are assigned to each element. During the simulation the environmental wind field is used to calculate aerodynamic forces over the full surface of the blade. The APS tool simulates the thrust force of the APS fans by using the APS controller logic and inputs from the other substructures. This analysis was key to understanding the expected performance of the APS when larger blades are lifted under offshore environmental conditions.

Onshore prototype testing was conducted at GE's prototype farm in Lubbock, Texas with the Sierra platform 68.7m blade. Pictures of the design are confidential and can be found in Figure 5 in Appendix A. APS functions tested at this time were the reaction to different wind conditions, SBI control during operation with and without a blade, and safety systems. Results for this testing are confidential and are shown in Figure 6 in Appendix A. During testing, data was collected to assess the functionality of the APS and its ability to maintain blade stability. Multiple blade lifts were completed where blade root displacement data was gathered at different heights, winds speed and wind directions. The data was then compared to the results generated by the analysis model for model validation. Results of this validation are confidential, and the results of a validation case are shown in Figure 7 in Appendix A. It should be noted that final approval of the model validation is still open. Due to weather and budget restriction limited model validation data was collected during field testing. At this point of the validation, using what data that was collected, there are no indications that the simulation is not modeling the system appropriately, but there is not enough data to fully validate all use case conditions. The plan is to continue collecting data through the onshore product development program that is being launched as an offshoot of the project.

The final phase of this project was to create a conceptual design for the offshore Haliade X platform with a 107m blade. Pictures of the design are confidential and are shown in Figure 8 of Appendix A. This concept needed to account for different installation procedures to those of onshore systems, the larger size of the SBI tool and blade, and different environmental factors in offshore farms. Leveraging the work done in the onshore phase of this project the design requirements, FMEAs and EHS and Product Safety evaluations were updated to reflect the offshore installation setting. Using the analysis modeling methodology created in the onshore phase, the needed APS thrust capability was determined for the larger 107m blade and offshore wind conditions. Due to the significant increase in needed thrust capability, additional fans were added to the APS resulting in the offshore final design having four fans, two on either side of the SBI tool. The interface of the APS to the SBI was able to reuse the current tagline arm interface to allow for easy transition to APS use.

With the offshore conceptual design finalized, the full power and moment simulation was run multiple time for various wind fields looking at the blade position deviation to confirm the maximum blade root displacement requirement was being met. The results of this simulation are confidential and can be seen in Figure 9 in Appendix A.

2 Project Takeaways

This project set out to improve three categories of problems associated with the use of the SBI tagline system for offshore installing and repairs. These categories are safety, time, and cost.

2.1 Safety

With current single blade operations, the horizontal taglines used with the SBI tool, can only keep the blade from swinging away from the crane. This means if the wind shifts from the ideal direction, the blade and/or SBI tool could swing back towards the crane without a means to stop it. This could cause damage to the crane, blade, or cause injuries to personnel onboard the JUV. With the application of the APS, the possibility of this issue is greatly reduced. During blade lifting operation the APS controls system monitors the movement of the blade. If the movement of the blade reached a set threshold the controls system is triggered to calculate the individual fan thrust demand to counteract the movement. The APS thrust fans can generate thrush in both the forward and aft direction allowing for full 360 degrees of horizontal positioning control, whereas the current horizonal tagline system can only pull one or two sides of the SBI tool toward the crane.

The next issue is that the installation of taglines is complex and labor intensive with significant dangers involved, which increases the likelihood for injury. These dangers can include working at height, electrical cabinet installation hazards, and working with and around steel wires. The TRIR tagline injuries onshore is 0.03. GE’s offshore business does not report the details needed to calculate the TRIR. The assumption is that the injury rate would be similar between offshore and onshore tagline use. This amounts to 6 recordable incidents in a year. Most of the recordable incidents involved trips and crush injuries when dealing with taglines. The offshore APS concept development in the project eliminates the need for horizontal taglines. This reduced the number of tagline winches from four to two. While this does not fully eliminant all tagline winches the reduction of worker exposure to taglines is anticipated to result in a decrease in related injuries.

2.2 Time and Cost

The next two areas of improvement are time and cost and are interrelated. The current tagline system takes 2-3 additional days to mobilize and demobilize for each repair operation. Additionally, once the JUV is onsite, the taglines require significant testing, troubleshooting, and maintenance to keep them operating appropriately. The additional time for the mobilization and demobilization of the taglines means that the JUV must be rented for those additional days which is costly. For unplanned maintenance, the delay in getting the JUV ready to deploy can impact the uptime and AEP of the turbines, which costs the customer money. With the use of the APS, and in turn elimination of horizontal taglines, it is expected the time associated with the mobilization and demobilization could be decreased by 50%. Using the time observed to install and remove the APS during onshore prototype testing, mobilization and demobilization is expected to take approximately 1 day. However, it should be noted that unlike the current horizontal tagline system, the APS is installed and removed during SBI tool mobilization and demobilization activities. This means APS setup is completed before the SBI tool is loaded onto the JUV and removed after the SBI is offloaded once operations are complete. Given the anticipated time savings the use of the APS system is expected to account for $275,000-$400,000 in cost savings per deployment.

3 Milestone Payment Schedule

3.1 Schedule Update

D4.2 deliverable, Final Report, is complete.

3.1 Progress With Respect to Milestone Payment Schedule

Associated Deliverable(s)	Forecasted Due Date	Percent Complete
D0.1.1: Quarterly Reports	M3	100%
D0.1.2: Quarterly Reports	M6	100%
D0.1.3: Quarterly Reports	M9	100%
D0.2: Brief report summarizing project kick-off meeting	M2	100%
D0.3: An agreed upon list of members of the Advisory Board, summaries of Advisory Board discussions	M2	100%
D0.4: A brief report regarding the project completion meeting	M13	100%
D0.5: Annual metrics Report	M12	100%
Task 0 Total		
D1.1: Design review results report	M5	100%
Task 1 Total		
D2.1: Report on testing outcomes and lessons learned	M10	100%
Task 2 Total		
D3.1 Report outlining adaptation scope, design requirements, ROM cost, commercialization timeline	M11	100%
Task 3 Total		
D4.1: A draft version of the Final Report	M12	100%
D4.2: A final version of the Final Report	M12	100%
D4.3: DOE required closeout reporting per Exhibit F	M12	
D4.4: Market Engagement Report	M12	
Task 4 Total	**M[12]**	

Appendix A. CONFIDENTIAL: Project Details

The pictures in this Appendix illustrate key portions of the conceptual design and have been removed from the public version of this report.

Figure 1 Current Offshore Blade SBI Equipment

Figure 2 APS Functionality Diagram

Figure 3 Model Substructures

Figure 4 Illustration of Simulation Wind Field

Figure 5 Onshore Prototype During Testing

Figure 6 Test Results

Figure 7 Model vs. Measured Data Comparison

Figure 8 Offshore Concept

Figure 9 Blade Stability Analysis Results