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I Introduction

To ensure the wind energy industry continues to expand, it is vital that engineers understand the various requirements of wind farm development. This can be especially complicated for the design of offshore wind farms. Resources such as BOEM provide up to date information on major factors the influence the development of offshore wind farms. The factors that heavily impact the design include regional wind resources, bathymetry, the soil type of the ocean floor, maximum wave height, etc. In the context of the competition, these constraints were considered when determining the optimal lease blocks. The sites that are outside of occupied areas and sit within promising wind resource zones are blocks A63 and A52. These blocks mark the lease areas chosen for the preliminary design of the wind farm. The turbine layout and type are outlined below, as are the specific layers used to choose these two blocks. The current energy output of the preliminary wind farm design is 190 MW.

II Wind Turbine Type, Hub Height, and Rotor Diameter

Most offshore wind turbine manufacturing facilities are located in Europe which would lead to large costs in the transportation of components. Additionally, the Jones Act prohibits foreign vessels from "loading cargo and personnel in US ports and then transporting them to a US offshore wind farm construction site," as described by the Douglas-Westwood Project Team (Douglas-Westwood, 2013, pg 13). This is currently the case with the first offshore wind farms being built on the Atlantic coast in that components must be staged in Canada, resulting in larger costs and longer construction times. This could change as Siemens Gamesa is building their first offshore wind turbine factory in the United States in Portsmouth, Virginia (Sidersky et al., 2021, par. 1). This would save considerable time and money for the project, due to reduced lead times (Stromsta, 2020, sec. 2). Hence, the selection of the Siemens Gamesa SG 14-222 DD offshore wind turbine is the most appropriate. The turbine features a 222-meter rotor diameter with a nominal power rating of 14 MW and up to 15 MW of capacity with their Powerboost technology “SG 14-222 DD”, n.d. Furthermore, the SG 14-222 DD offshore wind turbine has a site-specific hub height, which allows for better compatibility with our preliminary site design. Creating a 600 MW wind farm requires the construction of 40 wind turbines of this classification, at minimum. Serial production of the SG 14-222 is set for 2024.

III Interconnection Site on Coast

The PH Robinson substation in Bacliff, Texas was selected as the on-coast interconnection site. The substation has a minimum voltage rating of 69 kV and a maximum of 345 kV. This is necessary due to the size of the proposed wind farm and the transmission voltages from the wind farm to the electrical grid. Current offshore wind turbines have collection systems ranging from 34.5kV-66kV which is stepped up to 138kV-220kV by an offshore substation to reduce cable losses in transmission lines leading to the onshore substation. After reaching the onshore substation, the voltage is stepped up once more to 345 kV to match the transmission voltage of the electrical grid. According to J. Green et al. In a 2007 NREL conference report, “This voltage level is typical of a transmission system that can receive 500 MW of generation" (Green, Bowen, Fingersh, et al., 2007, pg 2). With our current preliminary design, the total power output is 190 MW. While this is much lower than our initial goal of 600 MW, the team plans to continue expanding the design to increase the final energy output. It is also good practice to choose a substation that allows for the future growth of a wind farm. So, the selection of the PH Robinson substation is appropriate in that the increased cost in transmission cabling due to the increased distance from the wind farm to the substation is balanced by the ability to expand the wind farm design.

IV Transmission Plan

Having a robust transmission plan is critical to delivering as much energy as possible from the wind farm to the consumer. There are two critical portions to this: inter-array and export cables. According to the *Assessment of Ports for Offshore Wind Development in the United States*, “inter-array cables connect the wind turbines into strings and then connect the strings to the offshore substation” (Douglas-Westwood, 2013, pg 14). “Export cables transmit the electricity from the offshore substation to the designated onshore landfall point” which in our case is the PH Robinson substation in Bacliff, Texas (Garrad Hassan America, 2014, pg 16). From a study conducted by Atkins, a design, engineering, and project management consultancy, it was found that 66kV inter-array cables are preferable to 33 kV (the most common in the industry currently) for large wind farm projects for several reasons. 66kV cables have the possibility of carrying “double the power with only a small increase in its cost” (Neumann et al., 2014, pg 6) resulting in fewer cables needed and fewer offshore substations. This results in significant cost savings and smaller energy losses which is preferable. Again, it is important to note that while the current energy output of our wind farm is 190 MW, the team will continue to expand the design to reach high power output values closer to the ideal 600 MW. Thus, a 66 kV inter-array cable system will be implemented.

For export cables, there are primarily two types of transmission: High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC). HVAC is the most economical for distances shorter than 50 km while HVDC is better for distances above 80 km (Green, Bowen, Fingersh, et al., 2007, pg 2). Because the distance from our wind farm to the onshore substation is 82 km, we selected an HVDC transmission system. This will utilize mass-impregnated paper-insulated transmission cables which are capable of transporting voltages in the range of 138-220kV, the range we plan to step up to at the offshore substation ("Foreign-Trade Zone #36: Port of Galveston, TX - official website", n.d., Tb. 1), and are produced in sufficient lengths to reach our substation.

V Environmental Considerations

This project must conform to federal, state, and local regulations to be approved for construction. Specific environmental laws such as the National Environmental Policy Act, the Marine Mammal Protection Act, and the Endangered Species Act serve to protect the environment from excessive harm. Special care will be taken to mitigate the project's impact on sensitive species and sensitive ecosystems in the project area.

Data from the NOAA fisheries website was collected to identify Essential fish habitats in our construction zone. In addition to this, regional experts from the Southeast Regional Office and the Atlantic Highly Migratory Species Management Division should be consulted for detailed reports on the fish species in the area. Our area does not contain any habitat areas of particular concernFisheries, n.d.

One of the primary risks for marine mammals is the high levels of noise generated during construction, especially during foundation construction. High levels of noise can pose severe health risks for marine mammals. A stationary resonator system is one option to mitigate high levels of noise.Severy M., n.d. Additionally, construction can be scheduled for times of low marine mammal activity in the area. Marine mammals are protected from injury or harassment under the Marine Mammal Protection Act.(n.d.)., 2021

Endangered species such as the Loggerhead and Leatherback turtle must be treated with particular caution. While they appear in relatively low density around our area, there is a possibility of interacting with them during construction.

The construction period is temporary, therefore it should not significantly impact the environment. Once the turbines are installed, they may even act as additional habitats for some species. Degraer, 2017

VI Hurricane Risk

This area of the gulf has seen three category 4 hurricanes pass directly over our site and has the potential to see category 5 hurricanes "An ocean of information", n.d. A category 5 hurricane means there are sustained wind speeds (for over 1 minute) greater than 157 MPH. Winds at this speed are likely to cause damage to the wind farm infrastructure. Therefore the probability of a storm event like this will be considered in the economic analysis of the project. Buoys based in the Gulf Coast (Lat: 25.790, Long: -93.666) recorded an average wave height of 1.23 meters between 1992-2008 (Appendini et al., 2014, pg 1622-1623).

VII Layers

The following layers were used to determine available lease blocks outside of inaccessible zones. Marine Cadastre provides this information to the public with various layers available in its National Viewer "An ocean of information", n.d.

VII.A OCS Oil and Gas Pipelines

This data describes the location and size of oil and gas pipelines that carry these fuels from the Outer Continental Shelf located in the Gulf of Mexico. This data is updated and maintained by the Bureau of Safety and Environmental Enforcement.

VII.B OCS Oil and Natural Gas Wells

This data set marks the locations of oil and gas wells that were "drilled for exploration and/or extraction," as defined in the ArcGIS directory. As these areas have removed portions of the ocean floor for fuel extraction, they are no longer available for wind farm development.

VII.C Shipping Lanes and Transportation

NOAA provides shipping traffic data that defines the flow of traffic and areas of safety concern. As shown in Fig.1, the outlined purple areas in the Gulf are traffic lanes. Wind farms must be placed outside of these traffic zones so that there is minimal disruption to shipping lines. Blocks A63 and A52 are both outside of demarcated lines of traffic.

VII.D OCS Drilling Platforms

Drilling platforms are built for harvesting underground fuels. The wind farm must be built away from these platforms to provide adequate spacing away from these structures, especially if they are in use. However, it is worth considering in the economic analysis of building the wind farm if it is possible to buy a rig located in OCS lease block 288. This could serve as a station for the wind farm maintenance crew.

VII.E Military Operating Area Boundaries

This data defines the zones of the United States Military's activities. The most significant zone within the Gulf Coast is the New Orleans OPAREA which is not included in the lease block area provided by the CWC. The other point of concern is formerly used defense sites where there are unexploded ordinances. The largest area is outside of Galveston, Texas, and ends just at the top left corner of the available lease blocks. It was therefore considered prudent to choose a lease block on the bottom edge of the lease block zone, away from the former defense area.

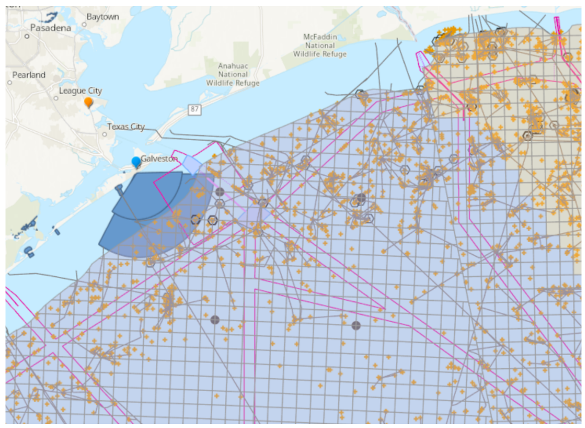


Figure 1: All Layers *Orange Marker: PH Robinson *Blue Marker: Norton Lilly *A63 and A52 Stacked Vertically Bottom Left Corner

VIII Turbine Type

Based on a study of offshore wind farms from BOEM, we have found that the T280 is the most common type of turbine with a T257 being the second most common. Because of the possible availability of a turbine in the class T257 from Siemens Gamesa, we have chosen this as our primary type of turbine(BOEM, 2020, pg 24). This will allow us to reduce the need for European parts due to the aforementioned possibility of a new Siemens Gamesa factory. While we chose the turbine to be the SG 14-222, this was not available for analysis in Furow. So, in order to get an idea of the energy output of the wind farm using Furow and to implement Gamesa products, we used the Gamesa G132 5.0MW Class S offshore hub height 94 m turbine (solely for initial analysis and site layout within the software).

IX Foundation Type

We first considered the most common types of foundations including monopiles, floating structures, and jackets. Our first concern is whether the foundation can adequately support our turbines. Wed find that the soil conditions at the Gulf Coast of Mexico are are not conducive for the monopile foundation type. The depths of the leases are also such that there will not be a cost-benefit to creating a floating wind farm as the ocean floor is between 20 - 50 m below the surface. For this reason, we have chosen a jacket foundation type in agreement with BOEM's recommendations. (BOEM, 2020, pg 16).

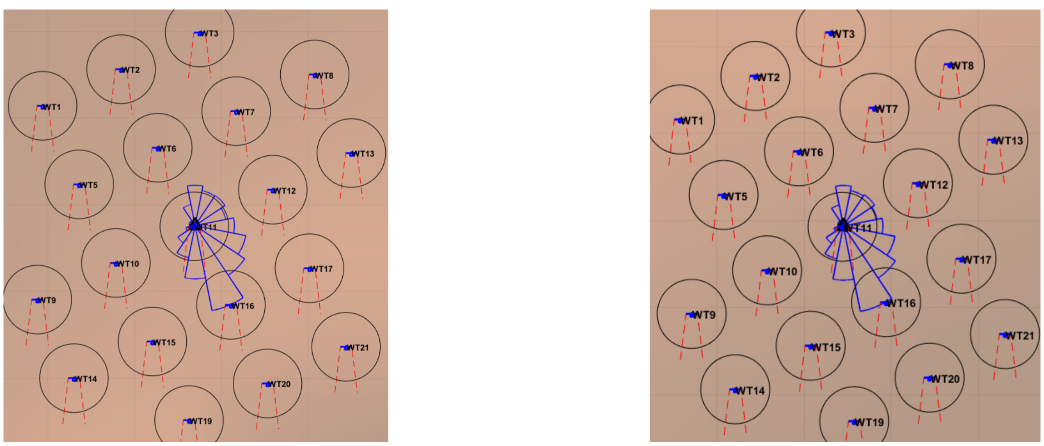
Second, we assessed the environmental impact associated with a jacket foundation. Starting with the installation, we recognized that jacket foundations have a lower footprint than that of gravity-based foundations. This means that the overall damage to the ecosystem can be mitigated. The fact that jacket foundations are temporary allows for the possibility of micro-sitting resulting in the ability to avoid sensitive and complex habitats. It can also be shown that the noise from the installation of the jacket foundation is comparable to that of other pile-driven foundations, giving no distinct disadvantage. In order to further reduce the the environmental effects of the foundation during operation, there is evidence that it could double as an artificial reef. This is assisted by the fact that jacket foundations inherently have a larger surface area than other foundation types based on their lattice of steel. Finally, it is important to consider wake effects. Due to the low density of these structures, there are minimal wake interferences compared to more traditional foundations such as monopiles. In conclusion, due to the increased surface area of the jacket foundations, similar noise of installation, and better wake characteristics, we have settled on the use of the jacket foundations in our wind farm (Boem, 2020, pg ES3, 32–34)

X Lease Area Block: A63 and A52

In order to determine the optimal space for our wind farm, we filtered through various activities and previously built structures that exist in the Gulf Coast. This started with the overlay of the shipping lanes and continued through analysis of the oil and gas pipelines. With the simplest option to choose a block with no added obstructions, we have narrowed down the choices substantially. Next, we looked for blocks that are close together to reduce transportation costs. The best choice by far are blocks A52 and A63 which contain no added obstructions and are adjacent to leasing areas with minimal restrictions.

XI Preliminary Site Design

With the lease blocks chosen, we can start designing the wind farm. As a basic method, we opted to align the two wind farms so that the rows are perpendicular to the direction with the highest frequency of wind. Spacing the turbines by 1000m which is greater than the suspected wake area of the selected turbines, we placed as many turbines as possible in the lease block. The alignment of the wind farms and their wind roses are overlaid in Fig.2. We are then able to create a wind farm where the rows receive relatively similar amounts of wind. Finally, to model our wind farms we have chosen the Jenson wake model Furow Wind Software Etulos Solute, S.L, 2019.



(a) A52 **(b)** A63

Figure 2: Preliminary wind farm design for blocks A63 and A52

XII Energy

Both the wind farms for block A63 and A52 are 95 MW capacity with 19 wind turbines each. The array yield was also found to be 279797.4 MWh and 278803.0 for A63 and A52, respectively. We then calculated approximate conditions for energy production using Furow software. As publicly available wind resource data is limited, we assumed several metrics. These values, such as standard deviation per measurement, were set using the recommended values provided by Furow. According to Furow the arrays have 92.2588% and 92.0177%, respectively, showing that we have a high possible yield of energy. While we were able to attain energy roses, the values were based on initial assumptions that can be improved with more research. Therefore, the team will continue to get more accurate data (especially regarding standard deviation), to have better energy yield.

XIII Ports

XIII.A Staging, Construction, and O&M

The Port of Galveston is the selected sight for staging, construction, operations and maintenance (O&M). According to a study conducted by Garrad Hassan America Inc. for the Department of Energy in 2014, a port assessment of the Port of

Galveston was conducted. The paper concluded that the port requires improvements costing approximately $6.4 million (assuming 2013 prices) to satisfy the port infrastructure requirements necessary for the large offshore wind projects (4000 MW) planned from 2014-2030 (Garrad Hassan America, 2014, pg 123). This would include increasing the areas available for turbine storage and jacket foundation storage. Despite the large upfront costs, the site is favorable due to its close proximity to the selected site for our wind farm. Furthermore, because our wind farm is only 190 MW, the current available space is satisfactory. Within the Port of Galveston, Norton Lilly International (Fig. 1) has the necessary port space and machinery to load and offload wind turbine components as well as over 10 years of experience with project logistics in the wind energy sector. The staging sites are sites 1-A and 5 “Foreign-Trade Zone #36: Port of Galveston, TX - official website”, n.d. In terms of O&M, there are no port requirements other than being in close proximity to the wind farm in order to achieve quick response times years ago en Community et al., 2016. Thus, the Port of Galveston will satisfy this requirement for the necessary O&M vessels that can be docked there.

XIV Vessels

XIV.A Survey

For an offshore wind project to commence there are typically three types of surveys that need to be done. "Environmental surveys can be completed by vessels equipped with sensors or by autonomous underwater vehicles (AUVs), both of which are readily available on the market ... Next are geophysical surveys which include seismic surveys, bathymetry, seabed features mapping, stratigraphy (geological layering) and analysis of hazardous areas"(Douglas-Westwood, 2013, pg 54). These vessel types can be small and are readily available as well. Finally, geotechnical surveys must be completed. This includes "drilling of sample boreholes at proposed foundation locations and cable routes, penetration tests for foundation installation and jack-up operations and plough trials for cable-lay operations"(Douglas-Westwood, 2013, pg 54). These can be completed using specific "survey vessels" or "fixed platforms with drilling equipment". Such vessels are readily available due to the prominence of the oil industry in the Gulf of Mexico. Crowley Shipping company has the necessary vessels to complete the surveying of the lease area Hewitt, 2021.

XIV.B Installation

Installation of Siemens Gamesa’s 14 MW turbine calls for a new class of wind turbine installation vessels (WTIV) that are capable of installing wind turbines of 12 MW or greater. According to the Offshore Wind Market Report: 2021 Edition published by the U.S DOE, there are currently only 3 vessels on the market capable of installing such turbines, those being the Innovation, Scylla, and Pacific Osprey from Germany, Panama, and Cyprus, respectively (of Energy. Office of Energy Efficiency et al., 2021, pg 70). This poses an issue due to the Jones Act. There are 4 more vessels currently being built that will be capable of lifting these large wind turbines, one of which is the Charybdis, which is being developed by Dominion Energy in the US and is expected to be finished in 2023. This is significant as it is Jones Act compliant. This would be the best option, but it will only be available in 2026 as it will be used for the Coastal Virginia Offshore Wind Farm to start Hewitt, 2021. If this is not a viable option, the aforementioned foreign vessels will need to be used and will have to be stationed in nearby Mexico, while transport vessels transfer the components from the Port of Galveston to the WTIVs. Another possible option is stationing the WTIVs at retired oil platforms close to the wind farm so as to reduce travel time.

As for transporting the jacket foundations, they are typically transported on flat top barges or speciality transportation vessels (Boem, 2020, pg 7). Crowley Shipping Company has the necessary flat top barges for this project Crowley, 2021. Finally, cable laying vessels will also be needed. There are currently “no US-flagged cable lay vessels in operation today, but cable-lay vessels are available in the global marketplace” (Douglas-Westwood, 2013, pg 59).

XV O&M

Operation and maintenance vehicles are easier to come by compared to installation vessels. Crowley shipping company is developing U.S. flagged Service Operation Vessels (SOVs) in conjunction with the Danish shipping company ESVAGT (the leading SOV operator in Europe) crowley, 2021. These vessels will be sufficient in transporting crews to the turbines to perform maintenance on them.

XVI Conclusion

While we are continuing to grow our knowledge of wind farm design, it is important to recognize there are are an infinite number of factors that can influence the success of these developments. The analysis of wind farms is a field that will continue to expand and improve.

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