Improving Multi-Use Port Facilities through Key Design Parameters

Robert Taylor[1]

[1]Bardex Corporation, USA; rtaylor@bardex.com

Abstract: Current port infrastructure globally is inadequate to meet the simultaneous demands across shipping, offshore wind, military complex, and private and commercial vessel build-and-repair industries. Successful shiplift and floating offshore wind energy implementation and operations facilities must address six core factors of port design: geology, geometry, target market, operational objectives, engineering / procurement / construction (EPC) plan, and financial plan. In this paper, geology and geometry are discussed. Geology drives the cost of these infrastructure projects. Site geometry determines the transfer system options, yard capacity, and revenue generation potential. Consideration of geology and geometry early in the design process significantly improves the likelihood that infrastructure investments will be financially viable and well executed, providing the expected economic benefits to regional economies.

Keywords: offshore wind, ports, infrastructure

Introduction

Global energy production is changing to address the effects of carbon emissions on the climate. Every country with coastlines bordering major bodies of water is in some stage of planning or actively replacing land-based fossil fuel generation with marine-based wind power generation. This systemic change in energy production is driving the need for investment in port infrastructure to enable deployment of offshore wind energy production infrastructure and provide support for future operations and maintenance of these assets. Currently, this transition is focused on shallow-water fixed-base structures supported on monopiles and jacket structures. In 5 to 10 years this market will expand to include offshore floating wind generation. Eventually, thousands of these devices will be operating along coastlines globally, generating the gigawatts of electricity needed to power modern industrial economies. All of this development will occur from repurposed port facilities, many of which are currently engaged in legacy energy production and maritime trade. Efficient planning of multi-use port facilities is essential to securing the success of this economic transition. Most importantly, well-designed port infrastructure projects will support the entire life cycle of offshore wind energy production and simultaneously provide regional economic benefits and employment over many decades.

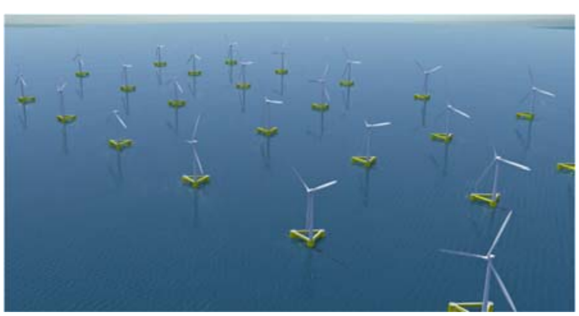

Figure 1 Life cycle solutions are required to support high volume projects.

Offshore Floating Wind Implementation

The history of offshore energy production development begins with offshore oil and gas. Understanding this history informs the design process of infrastructure to support efficient deployment of utility-scale offshore wind generation. Similar to offshore wind power, oil and gas development began onshore, moved to fixed-base shallow water and eventually to floating production. Where the pattern diverges is the quantity of deployments, which decreased inversely with water depth. Accordingly, implementation sites were developed with minimal infrastructure, as these facilities were designed to produce and launch large assemblies at low volumes. There was no additional need for these facilities beyond the implementation stage of development. The resulting designs controlled costs by minimizing site development and utilizing technologies that could be dismantled and relocated to other sites for similar applications.

Offshore wind implementation is following a similar trajectory, with some key differences. Many ports are currently participating in the development of onshore wind as points of embarkation for towers, blades, and nacelles. These ports are transitioning from onshore wind support to shallow-water offshore wind implementation hubs. Unlike onshore development, offshore development comes with increased marine traffic and demand for vessel support services.

These ports will continue to serve as embarkation points for towers, blades, and nacelles for offshore fields. What is changing is the fabrication and delivery of monopole foundations. These foundations are more cost-effectively built locally and offer the opportunity for local economic growth. Unlike historical shallow-water oil and gas development, thousands of these relatively small foundations are required, and production rates are measured in units per day, not months or years. Reaching this level of production requires a wellorganized manufacturing plan and load-out / launch system.

Development of floating wind is moving from the testing phase to implementation, and generation capacity per unit is growing. The key difference between this emerging market and deep-water oil and gas production is quantity. Hundreds of foundations are to be deployed over a period of a few years. Launch rates are measured in units per week rather than years. The nacelle, tower, and blade supply chain is unchanged. The foundations will be produced in the local economy using steel and concrete. Final assembly, fit-out, and launch will occur within the ports at large purpose-built implementation facilities.

The entire life cycle of offshore floating wind infrastructure should be considered in the design of the implementation infrastructure. **Unlike any other offshore energy asset, floating offshore wind infrastructure can be detached from permanent moorings and towed back to port for maintenance, repair, life extension, and eventual recycling of any component of each asset.** This presents an opportunity for multi-use infrastructure investments that provide regional economic benefits for decades.

One of the lessons learned from oil-and-gas implementation infrastructure history is that the life cycle needs of these assets were not addressed. Decommissioning capability of legacy assets can be integrated into offshore wind implementation infrastructure where required. The port infrastructure necessary to remove and recycle legacy oil and gas production assets is identical to the infrastructure necessary to deploy and operate offshore wind power generation.

Key capabilities of multi-use port infrastructure are:

- Efficient use of available space
- Compatibility with concurrent port operations
- Life cycle operational support

The life cycle design approach begins in the implementation phase of offshore power generation deployment. In this phase, the facility serves as a factory, building up, fitting out, and launching complete assemblies for tow-out and mooring at sea.

After implementation, the facility serves as a refit and repair hub for the vessels, installing and maintaining the offshore assets as well as the floating foundations and generation equipment. Heavy-lift and load-moving equipment and infrastructure designed to launch and retrieve floating wind foundations will also launch and retrieve vessels.

Repairing elevated wind power generation equipment at sea is a high-risk undertaking that comes with a high-cost premium. This work can be undertaken only during optimal weather conditions. Offshore wind generation facilities are sited in locations with consistently high winds; consequently, weather windows suitable for major repairs at sea will be very limited.

Floating wind generation assets can be towed back to port for rapid nacelle, blade, and tower exchange. The asset can be returned to service and the generation equipment can be repaired in a controlled environment. This method reduces both cost and risk. Delays due to weather and loss of generation capability are mitigated.

The open ocean marine environment will inevitably cause damage, necessitating repairs. The ability to remove the floating foundations for maintenance and repairs will extend the life of these assets and improve the return on investment for operators.

The need to remove and recycle legacy offshore energy production equipment both in oil and gas production and early-stage fixed-base offshore wind generation is significant and will increase in the coming decades.

The implementation facility infrastructure can also serve as a module offloading facility for onshore wind, hydrogen production modules, and other industrial development that will accompany the energy economy and will develop concurrently with utility-scale offshore wind capability.

The development of offshore floating wind foundation technology is similar to the Liberty ship construction during World War II. Like the Liberty ships, there are offshore wind floating foundation designs constructed from both steel and concrete. The concrete designs have a smaller footprint and a greater weight. The steel foundation designs have a larger footprint and are less than half the weight. The implementation facility infrastructure required to support these design methodologies is very different.

The steel monopole and floating foundation components are constructed outside of the port facility. Final assembly and integration occur at the port implementation facility.

Concrete floating foundations are constructed entirely within the implementation facility. Facilities constructing these structures include batch plants, reinforcing bar bending shops, and multiple casting bays.

All these important roles require safe, low-carbon release methods for moving large assemblies and power generation components through an assembly line process.

Successful shiplift, OmniLift™, and floating offshore wind energy implementation and operations facility designs must address six core factors of port design: geology, geometry, target markets, operational objectives, engineering / procurement / construction (EPC) plan, and financial plan.

Every offshore wind implementation facility shares two common design challenges: the need to support high ground pressures over large areas, and the ability to launch and retrieve foundations weighing up to 30,000 tons with 8- to 10-meter drafts into the water. Foundation engineering to support heavy loads in marine-adjacent facilities is always challenging and expensive. Designing and constructing these facilities in an era of rising sea levels increases both cost and risk. The underlying geology determines the type and cost of the civil foundations necessary to construct an offshore wind implementation facility.

Implementation facility civil designs must provide stable high-capacity work surfaces and create sufficient key side draft for launching and retrieving large floating structures.

Port facilities exist mainly in protected coastal locations. Ground conditions range from deep, soft soils to high bedrock. Locations with soft soils at depth have the advantage of being relatively easy to dredge; however, soil retention, sedimentation, and bearing capacity are a concern. High bedrock conditions provide excellent bearing capacity but are expensive to level and dredge.

Transfer System

When considering technologies for serial assembly and launch or concrete or steel floating foundations, the ground conditions inform the selection of technology. The assembly process, whether concrete or steel, requires a cost-efficient method of moving many heavy objects over a significant distance for a decade or longer. Heavy-load moving technologies appropriate for this application are self-propelled modular transfer (SPMT) devices, rail-based systems, and skidding-based systems.

SPMT systems offer both high-load carrying capacity and maneuverability. These systems are generally diesel hydraulic lifting units on pneumatic or solid tires. These systems are highly reliable and safe to operate. SPMT systems impart very high wheel-loading ground pressures during operation. The units are expensive to purchase and maintain. The need to improve large surface areas for operation is an important consideration where geology becomes a factor. In locations where soft or reclaimed soils exist at depth, the civil foundation cost will be high. In locations where soil-bearing conditions are moderate to high, the cost and risk are mitigated. SPMT units emit significant amounts of carbon during operations. Specifying more efficient Tier 4 and Tier 5 diesel engines and using synthetic fuels are possible ways of reducing emissions.

Figure 2 A rail based self-propelled transfer system.

Rail-based systems have moved heavy objects long distances efficiently for over two centuries. Rail-based heavy-load moving systems are widely used today for gantry cranes and ship handling. This technology is safe and reliable to operate. Rail-based systems feature high capacity and low maintenance costs. These systems are very economical in soft ground conditions. Foundation support is provided only where required along the rail path of travel. The configuration of the foundation structure can be adjusted to optimize use of materials over a wide variety of conditions. Sites with moderate to high soil-bearing values also benefit from the defined load path. Rail-based systems can be towed or self-propelled. Diesel or electric motive power systems are used in rail-based transfer systems. As with SPMT systems, using fully electric drive systems, clean diesel engine technology, and synthetic fuels is recommended to reduce or eliminate carbon emissions during system operation. For infrastructure investments made in the pursuit of offshore wind to reduce carbon emissions, there is an inherent obligation to consider every means of reducing operational carbon emissions.

Skidding-based systems have a long history in heavy-load moving applications; shipbuilding, jacket launching, and pre-cast concrete tunnel and caisson units are examples. These hydraulic-powered systems are safe and reliable to operate, and maintenance is minimal. Like rail-based systems, operation occurs along a network of skidding plate surfaces, allowing for efficient foundation support.

Figure 3 A low volume skidding system used for jacket loadout.

The primary disadvantage of these systems is operation speed. Historically, these systems are used in low-volume or one-time applications, where the low cost of facility construction and equipment is more important and speed of operation is not a consideration. The launch rates necessary to achieve deployment objectives for offshore wind require that operational speed be considered when selecting transfer technology.

Skidding systems are hydraulically driven and make use of diesel engines. The slow operational speed requires longer operating times than SPMT or rail-based transfer systems. Selecting fully electric drive systems, clean diesel engine technology, and synthetic fuels is recommended to reduce or eliminate carbon emissions during system operation.

Moving hundreds or thousands of large concrete and steel components weighing thousands of tons rapidly through construction, fit-out, and launch is a civil engineering challenge that must be solved to enable decarbonization of modern global economies. Investment in multi-use port infrastructure is a precursor to the deployment of industrial-scale offshore wind generation, necessary for operations and maintenance of the deployed assets, and essential for future decommissioning of these systems.

Available space within existing port facilities is limited and must be used efficiently. The geometry of the available space along with site geology informs the selection of heavy-load moving transfer technology for each site.

SPMT systems are very well suited to load-moving applications requiring high capacity and high maneuverability. SPMT transfer systems work very well when irregular site geometry requires multiple changes of direction at odd angles. In situations where this capability is essential to operations, SPMT systems may be the best and only option. Consideration should be given to the cost implications of providing adequate support of wheel loading along complex routes. Moving large objects along paths that require multiple small changes of direction is a slow process and has the potential to reduce the launch-rate objective for the facility. SPMT units are in high demand globally; however, there are only a few manufacturers. Availability and costs should be considered before selecting a site that requires use of these devices.

Rail-based and skidding-based systems are well suited to sites with regular geometry. Change of travel direction at right angles can be accomplished with either system. Sites with regular geometry that lend themselves to an efficient assembly, fit-out, and launch process will be less costly to develop and operate.

The technology and equipment are rudimentary. Rail-based and skidding-based equipment is custom built for each application. These systems can be procured from a wide variety of sources and are built from simple hydraulic and steel components available in most developed countries. These systems are "low tech" and have few moving parts, making them easy to design, build, and maintain.

Launch System Considerations

Launch and tow-out of offshore floating wind and fixed-base wind foundations require deep water adjacent to the implementation facility and access to harbor shipping channels for transit to the offshore wind project. Deep water close to shore rarely occurs naturally; dredging and marine excavation are typically required to create and maintain the necessary water depth. Geology and geometry also play a significant role in planning an efficient launch and retrieval infrastructure.

Graving docks and slipways are launch technologies that have a long history in shipbuilding applications, but they are not adaptable to serial fabrication and launch of floating offshore and fixed offshore foundations. These technologies are designed to service one vessel at a time; access for work and pollution control are challenging; and, most importantly, the existing infrastructure is not wide enough to host floating wind foundations. Graving docks are also slow and costly to operate and maintain.

Slipways are space-intensive devices, and transitioning a wide, heavy object from a horizontal surface to a sloped surface is difficult to accomplish safely and reliably. The shallow slope required, combined with the required float-off depth, necessitates a long marine railway. Such a railway would need to be wide enough to accommodate a 100-meter wide foundation.

Launch technologies proposed for offshore wind implementation and maintenance generally fall into two categories: submersible lift systems and vertical lift systems.

Submersible Launch Systems
Floating dry docks (FDD) are commonly used in launching applications; there are many FDDs that have sufficient lift capacity. Unfortunately, they do not have sufficient width. Existing FDDs are designed to handle ships, which have relatively narrow beams compared to length.

New FDDs similar in design to open-ocean heavy-load transport vessels are being constructed for the application that do have sufficient width and lifting capability to launch and retrieve large floating wind foundations. These devices are classed vessels, meaning they must be regularly inspected and maintained to be insured.

FDDs are slow to operate and have very high maintenance costs. These devices require carefully planned and executed ballasting operations to maintain stability. Transferring large objects from shore to the FDD is a slow and delicate operation, as the FDD ballast and trim must be continuously adjusted as the foundation is moved onto the vessel.

FDD operation is dependent on available water depth and tide change. Grounding beds for loading and dredged basins for submergence are commonly required to enable use of these devices.

Tidal change and flow impact operations. FDDs large enough to accept floating wind foundations will be anywhere from 80 meters square to 125 meters square.

Submerging a large FDD in a tidal flow zone requires the use of six or more tugs. A minimum of three is required to hold the FDD in position. Three additional tugs are required to control the floating foundation as it is lifted off the FDD.

This many vessels working in close proximity with lines connected to two objects is a complex and high-risk operation that can be undertaken only during daylight in optimal conditions.

Vertical Lift Systems
Vertical lift systems have been in industrial use in shipyards for over a century, primarily for their efficiency. Unlike other methods for managing marine vessel construction, maintenance, and repair, vertical lift systems can serve multiple client vessels simultaneously. Vertical lift systems offer the same efficiency advantage to the floating offshore wind industry. Launch and retrieval of multiple vessels or foundations per day can be achieved with this technology. These systems are also capable of supporting maintenance and refit of port tugs and offshore wind service vessels. This is essential for deployment, operation, and, eventually, removal of offshore power generation assets.

Figure 4 Examples of vertical lifting devices are the shiplift and the OmniLift™ Floater/Maintenance Vessel Launch and Recovery System. A typical lifting component is the chain jack, shown here.

Vertical lift systems for floating wind foundation production and launch are a solution where port and channel access will be impaired by FDD operations. Vertical lift systems of the size and capacity capable of launching floating wind foundations can be built into the shoreline and do not interfere with other port operations.

Vertical lift systems for vessel maintenance have capacities ranging from 2,000 to 20,000 tons. Conventional vertical shiplift platform dimensions start at 15 meters in width and 40 meters in length and increase to 30 meters wide by 180 meters long or more.

Bathymetry determines the operational possibilities of every project site. Larger vessels and floating wind foundations must have sufficient channel depth to enter and exit the vertical lift system. Typical drafts for vertical shiplift systems range from 5 to 10 meters. Floating wind foundations constructed of steel or concrete have drafts ranging from 10 to 15 meters or more.

Vertical lift systems capable of launching floating wind foundations must have a platform large enough to accommodate the foundation and sufficient lift capacity to transfer it into and out of the water.

Steel floating foundations are lighter in weight and larger in footprint. These foundations weigh from 4,000 to 10,000 tons and require square or rectangular platforms of 90 to 105 meters in width to launch.

Concrete foundations are heavier but more compact than their steel counterparts. Weights range from 8,000 to 28,000 tons. These foundations require square or rectangular platforms 60 to 80 meters wide for launch and retrieval operations.

Vertical shiplift platforms with spans under 30 meters are typically built using steel plate girders. The new generation of vertical lift systems purpose-built for floating offshore wind will utilize trusses. Efficient plate girders and trusses have a depth-to-span ratio of 1 to 10. The economic viability of a vertical lift system is determined by site geology; water depth, dredging conditions, geology bearing capacity, and soil retention method required to create a basin deep enough for operation of the platform.

Conclusion

Context is the key to determining the most appropriate technology for heavy lift and transfer operations. Geology and geometry define the costs and possibilities. Understanding these factors and how they inform selection of systems allows the designer to base decisions on a solid foundation of objective design criteria.