Reducing offshore costs through integrated design

DNV GL proposes Project FORCE, paving the way for future savings in offshore wind development

Chapter One-Executive Summary

Energy security and CO_2 reduction are vital for a sustainable energy future, but anyone following energy issues in the media will be aware that prices are top of many peoples' agendas. As the third element of the so-called "energy trilemma" faced by policy-makers, the cost of energy to homes and businesses is a major political issue. In particular, the political debates in countries such as Germany and the UK have a strong focus on the perceived cost implications of policies designed to promote new, clean energy sources such as offshore wind.

But making use of the wide-open spaces and fabulously rich wind resource of the sea has the potential to provide huge volumes of clean, domestically produced energy while simultaneously spurring economic growth and creating new jobs in the manufacture, installation and operation of wind turbines.

Compared to its land-based cousin, offshore wind is a new energy technology. This relative immaturity as well as the technical challenge of offshore wind means that it is currently around 50 percent more expensive to produce a unit of energy offshore than it is onshore. But the stronger, more consistent wind at sea means that there are real opportunities to narrow the gap and there are several government and industry-sponsored programs aimed at doing just that in the UK, Germany and Denmark — all leading countries in the creation of offshore wind sectors.

Adding to this important work, DNV GL plans to launch a cost reduction manifesto, to uncover opportunities for lowering the cost of offshore wind — and put them to work in the real world.

As the first stage of this process, project FORCE brought together a world-leading wind turbine design team tasked with completing a detailed engineering study, revealing the magnitude of the potential savings from a "joined-up" approach to the design of large offshore wind turbines and their jacket support structures.

Project Force: Cost Efficiency Through Integration

"Joined-up" or integrated design of wind turbines and their support structures is one of the most potent ways to save cost in offshore wind. Recognizing this fact, DNV GL brought together 25 expert engineers from cost modeling, offshore load calculations, blade design, controller design, drivetrain design and support structure design disciplines to get under the skin of cost-reduction. The FORCE team worked to integrate recent advances in offshore wind technology and demonstrate reductions of at least 10 percent to the cost of electricity generated by offshore wind.

The result of the work is four technologies for cost reduction — the "killer apps." All four of the killer apps proposed are classed as "near market," that is, they are expected to be deployable commercially within five years.

Collaboration Is The Key

Strikingly, none of these measures can be deployed by a single supply-chain player[1]. Indeed, in some cases issues of intellectual property protection, confidentiality and conflicts of interest mean that there may be resistance to innovation, even though the collective benefit of reducing cost — something which is vital for the future of the industry — is very large. A resolution to this apparent dilemma must clearly be found to enable the cost savings needed for a healthy and sustainable offshore wind industry. At the heart of the challenge is the way the costs and benefits of integration fall on the companies which make and install the various components of an offshore wind farm. Currently there is a misalignment of design-risk and cost-reward between the contracting parties, which is blocking innovation. The remedy to this is a swift transition towards a collaborative and integrated approach to the design, engineering and procurement of offshore wind projects.

The idea that cooperation between offshore wind supply-chain players is crucial to realizing cost reduction is not new. Collaborative contracting practices such as "alliancing" were encouraged in the UK's Oil and Gas sector in the 1990s[2] and are discussed at length in both The Crown Estate's Offshore Wind Cost Reduction Pathways Study and the UK Government's Cost Reduction Task Force Report[3]. Benefits including better alignment of incentives, risk sharing and cost reduction are all identified but few concrete actions have yet been delivered.

Reflecting the diversity of possible solutions to the collaboration dilemma, DNV GL presents the leading options for bringing engineers together to make cost reduction happen. On balance, we favor a Joint Industry Project (JIP) on integrated practices across design, engineering and procurement. This offers the greatest potential to unlock the cost-reducing power of an integrated and collaborative approach to offshore wind. Ultimately, whichever path our offshore wind industry takes, we believe that healthy levels of collaboration are as important as healthy levels of competition. Whilst we have made significant progress on the latter over the last few years, it is now time that we start acting like a mature industry — embracing both collaboration and integration.

Chapter Two- Project Force Crossing From Excellent To Outstanding: The Integration Of Design

Producing energy at the lowest cost possible is the goal that drives wind energy design. From the blades of the turbine through to the foundation at the base of the support structure, the cost of all of the components is assiduously minimized by experienced and talented engineers. However, until recently, the tools required to fully understand the interactions between the various components and sub-systems had not been brought together on a single design and analysis platform.

For example, the turbine manufacturer designs a turbine optimized to deliver the lowest life cycle cost possible before releasing technical information to enable the separate design of the support structure. The trouble with this approach is that the design of each element has subtle but significant implications for the design of the other. It may be possible to design a turbine with more advanced features that is, perhaps, slightly more expensive but reduces the loading of the support structure enough to save cost in the steel fabrication and result in a net overall saving.

By performing this kind of optimization exercise on the turbine/support structure system as a whole, any unintended conservatism resulting from isolated design of components can be eliminated — and cost saved.

Revealing The Potential: The Force Approach

Building on three decades of experience and careful modeling of wind energy technology, DNV GL has built up a suite of cost models. These models, which are all validated with real-world data, can be used in concert to optimize the design of each element of an offshore wind turbine as a single system from the seabed to the rotor tip without the need for lengthy and possibly incomplete design iterations.

By bringing together experts from all aspects of wind energy design and testing, using a full-system cost model to measure the outlays and benefits of their ideas, project FORCE has been able to identify and quantify cost savings for offshore wind that would otherwise have been missed.

Killer apps for cost reduction

The outputs of project FORCE center on four killer apps for cost reduction. The apps are technologies or practices that are ready (or nearly ready) to be deployed commercially and have the potential between them to reduce the cost of energy from large offshore wind by at least 10 percent.

Integrated Design

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Currently, wind turbines are being procured by developers under separate contracts to the support structures; this is a barrier to the integrated design approach and generally results in non-optimal designs, especially for the support structures. Integrated loads analysis not only saves cost, it also allows the identification and quantification of the cost savings from our three other killer apps.

Enhanced control

Offshore wind structures are not static, passive structures that simply have to withstand their environment. They are fundamentally dynamic and by means of active control technology are able to respond intelligently to applied environmental loads. project FORCE deployed DNV GL's world-beating capability in the technology and design of wind turbine control systems, developing an innovative approach to improving pitch control.

The power output from an individual turbine can be increased or decreased by altering the angle of the blades to the wind, known as the pitch. In the same way that the sails of a boat can be trimmed to respond to changes in the wind to keep the boat upright and sailing smoothly, the control system of a wind turbine changes the pitch of the blades in real-time. At the most basic level, the blades can change pitch in unison to try and smooth the power to the drive train and keep it from exceeding the turbine's rated capacity. More subtly, the blades can change pitch individually in order to actively reduce the loads experienced by the turbine and its support structure, allowing a leaner, more optimized design and a lower overall cost of the combined system.

While 1P individual pitch control — where each blade adjusts its pitch once per revolution (approximately eight seconds) — is widely used for state-of-the-art offshore turbines, project FORCE undertook cost modeling and dynamic simulations to understand the implications of doubling the frequency of adjustments to twice per revolution. So-called 2P pitch control can, in particular, reduce the twisting loads on the support structure and allows net cost savings to be made in the fabrication and installation of lighter components. In addition to improving the rate at which the blades' pitch can respond to changes in wind conditions, FORCE has also investigated the use of forward-looking LiDAR[4] to increase the ability of the wind turbine control system to anticipate changes and thereby respond faster.

Refined blades

The modern wind turbine was born on dry land and has had to adapt to its environment. Sharing the landscape with communities means that there are certain constraints which define the envelope within which onshore wind turbine designers can operate. One of these constraints is the level of noise that the turbine blades make — which in turn limits the speed at which the blades can rotate. The design implications of this constraint are hard-wired into many aspects of onshore turbine design, such as the aerodynamic shape or planform of the blades.

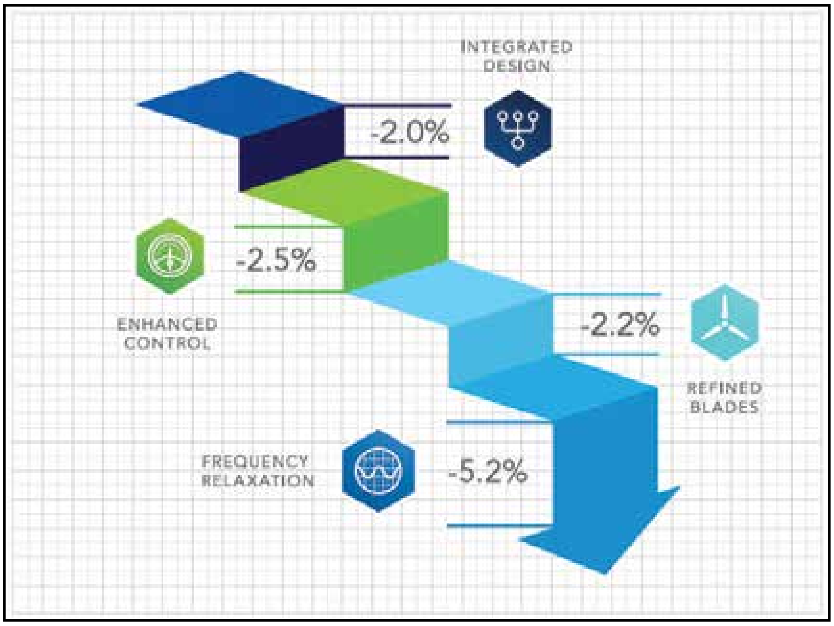
When engineers began to adapt onshore designs to the hostile and remote offshore environment, using onshore turbines as their basis meant that many norms and standards came with them, including some that dictated the speed at which the rotor tips move through the air to ensure noise levels were capped. But, miles from land, with no one around to hear the sound the blades make, it is quite possible to

Footnotes

1. Current wind turbine Original Equipment Manufacturers (OEMs) do not offer full Engineer-Procure-Construct-Install (EPCI) contract packages.
2. Tuft, V., 1995. CRINE - COST REDUCTION INITIATIVE FOR THE NEW ERA.
3. DECC, 2012. Offshore Wind Cost Reduction Task Force Report; The Crown Estate, 2013. Offshore Wind Cost Reduction Pathways Study, Available at: http://www.thecrownestate.co.uk/media/305094/offshore-wind-cost-reduction-pathways-study.pdf [Accessed February 28, 2014]

relax the constraint on rotational speed, altering the planform or shape of the blades to maximize energy output and reduce loads without such concern for noise.

When the project FORCE team looked closely at the design implications for the overall cost of energy of allowing a faster, slender blade, some interesting findings emerged. Although tinkering with the blade in this way does not fundamentally increase the amount of energy that can be captured, it does have some significant spin-off benefits for other parts of the system. For example, a faster moving rotor imparts its energy to the turbine with less torque — which means that drive train components can be potentially lighter and cheaper. It also means that, because slender blades are inherently more flexible, they are able to naturally deflect in response to changes in wind speed, reducing the potential for fatigue of the turbine and its support structures — again allowing cost savings to be made.



Frequency relaxation

All structures have natural or "resonant" frequencies and respond much more vigorously to excitation at these frequencies than at others. Alarming demonstrations of resonance include the destruction

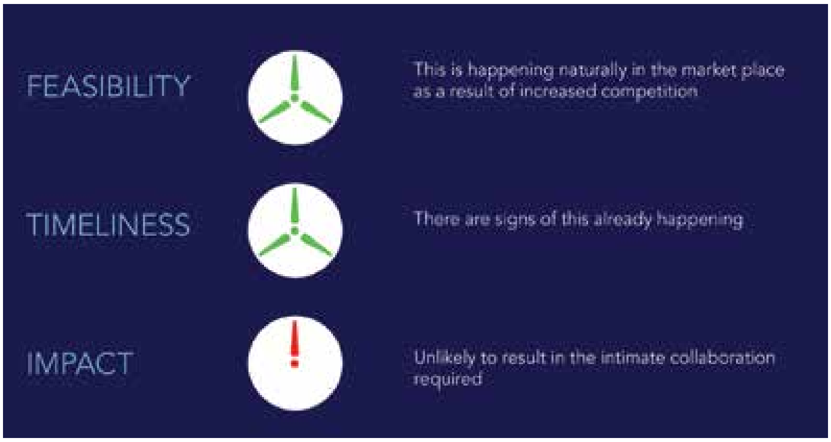


Figure 1: Option 1 — Market Forces

Figure 2: Option 2 — Buyer-Led Enforecement

of bridges in response to wind-induced vibrations or buildings becoming unstable due to fitness classes working out to a particular track.[5] Wind turbine structures are no different: Designers consider whether their structure will have a resonant frequency similar to the excitations or load variations likely to be experienced by the structure. Fortunately, it is relatively easy to predict since the major loading variations are associated with the rotation of the turbine blades. Designers of offshore support structures therefore take care to ensure that the structural resonant frequencies are constrained to be sufficiently far from the rotational frequency of the rotor — or its multiples.

This "design frequency constraint" is a highly effective way of minimizing the amplitude of vibration and hence severity of fatigue loading of the support structure. However, it also comes with a significant cost. Jacket designs which have lower resonant frequencies tend to have profiles with narrower footprints and be made of thicker steel cross-members — and are more massive. More steel means more cost and, when the jacket and tower can account for almost half of the capital cost of a wind turbine installation, even small savings could be significant. By carefully modeling the impact of a relaxation of the design frequency constraint, allowing a stiffer jacket with a higher resonant frequency somewhat closer to a multiple of the rotor rational frequency, the project FORCE team has found that the resulting structure with a wider footprint can result in up to 25 percent saving in steel costs. Clearly, the potential for net costs savings are very significant indeed.

Chapter Three- Making It Happen

The Offshore Wind Prisoner's Dilemma: A Game Of Trust

First conceived by mathematicians working on game theory in the 1950s, the "prisoner's dilemma" is a concept that explains why cooperation is not always easy to achieve. It neatly shows that, depending on the pay-offs of different outcomes, the most likely result of a "game" of two "players" (prisoners in the original version) is non-cooperation — even when it is in both players' interest to work together[6].

Designing, building and installing offshore wind turbines may not be a classic application of the prisoner's dilemma, but as a metaphor it certainly seems apt. We can think of the various parties in the offshore wind supply chain as the players in the game, and the

Footnotes

4. LIght Detection And Ranging – similar in concept to RADAR but using light rather that radio waves.
5. http://news.blogs.cnn.com/2011/07/19/scientist-tae-bo-workout-sent-skyscraper-shaking/
6. http://www.open.edu/openlearn/history-the-arts/culture/philosophy/the-prisoners-dilemma-detail
7. Whereas traditional contracting structures are predicated on the idea of competition between suppliers, "alliancing" refers to the cultivation of long-term collaborative partnerships between two or more suppliers across the supply chain and their clients. Alliancing arrangements can come in many variants; for instance, they can be project-specific, or apply more strategically to a number of projects. They can range from 'pure' collaborative structures to looser, more informal involvement at the project design stage.

mutually attractive outcome of lower cost offshore wind as the result of cooperation through the killer apps described in Chapter Two.

To make use of the insight afforded by this simple game theory example, we can take a look at which of the project FORCE technologies are likely to require collaboration between parties that may not occur spontaneously. The illustration overleaf, shows that the cost (and risk) of implementing the killer apps does not always fall on the same party as the benefits that accrue.

The key to unlocking these benefits is the Integrated Design app: the joined-up design of the turbine and support structure. The cost savings are real and achievable with today's technology: the only barrier is commercial.

Addressing The Barriers

There are several options open to the offshore wind sector that can potentially solve the dilemma. Here, we assess the options and score each of them for feasibility (how easily the approach can be implemented); timeliness (whether the approach can realize savings rapidly enough to impact the current generation of offshore wind farms); and impact (the potential of the approach to unlock project FORCE savings). The scoring is based on a traffic light system in which green means that the assessment of the feasibility, timeliness or impact is very promising, while amber indicates a note of caution and red indicates real problems.

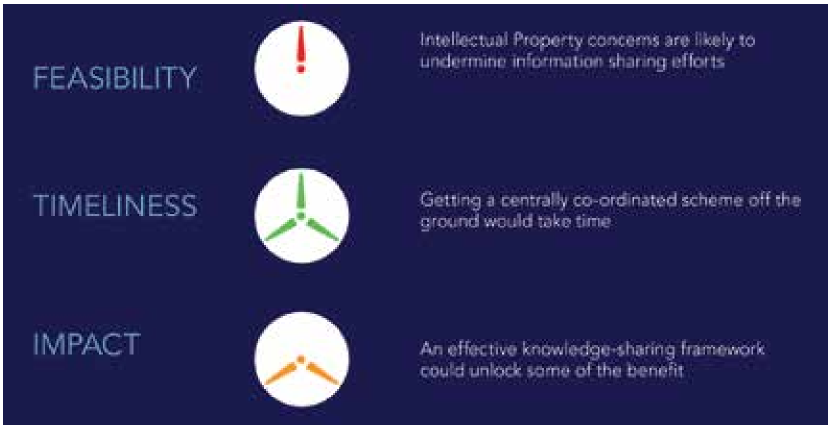


Figure 3: Option 3 — Government-Led Information Sharing

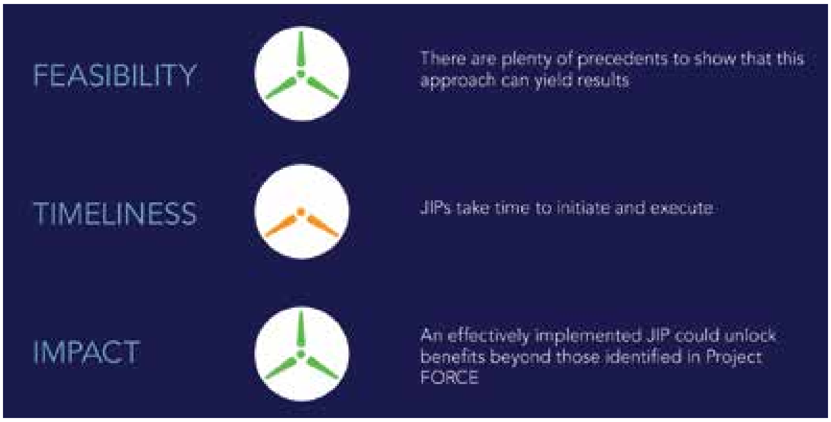


Figure 4: Option 4: "Jip" On Integration Of Design, Engineering And Procurement

Option 1:
Market Forces (Figure 1)

Perhaps the most obvious approach is to "leave it to the market." This strategy is consistent with the political push for cost reduction through competition being encouraged in some leading markets, most notably the UK and Denmark. But what would it actually look like — and is it a remedy to the collaboration challenge we have identified?

In fact, competition between turbine manufacturers is already leading to turbines that are marketed on their whole-system levelized cost of energy (LCoE). But to deliver the savings of the killer apps, the turbine designer must be able to directly influence the foundation design — which is not currently the case. And, while there may be an incentive for the turbine supplier to also take on the contract for the foundation, a contract barrier between the supplier and the foundation designer is likely to remain — meaning that the kind of intimate collaboration required to unlock the benefit of the killer apps is not readily possible.

Option 2:
Buyer-Led Enforcement (Figure 2)

Another strategy might be for the buyers of offshore wind turbines — the project developers — to make integrated design a condition of contact awards. For instance, when designing procurement exercises a developer could request tenders for an integrated turbine and support structure package. Scoring review criteria could be amended to favor truly integrated designs. More radically, project developers could only request integrated package tenders.

Option 3
Government-Led Information Sharing (Figure 3)

Given the "common good" nature of cost reduction, there could be a role for government to play in removing barriers to integrated design. This could be through regulation, which requires more integrated design practices or the publication of recommended practice documents. Alternatively, government could take a more active role, perhaps commanding the central collection and distribution of information.

Option 4

"Jip" On Integration Of Design, Engineering And Procurement (Figure 4)

A Joint Industry Project (JIP) could offer the framework needed to unlock the benefit of integrated design. Such a project would need to address contracting structures in order to better align risks and rewards, including perhaps a more complete exploration of alliancing options[7]. But, crucially, it would also need to define best practice guidelines for actually implementing an integrated approach to design and engineering much earlier in the project life cycle. By providing a widely accepted industry benchmark, the collaborative and integrated approach to design and engineering would, over time, become enshrined in industry practice. This would offer benefits beyond the turbine-support structure elements examined by project FORCE. Electrical infrastructure and installation practices are just two additional areas that would likely yield cost compression as a result of this approach. The guidelines could be road-tested in detail using a recently completed project as a baseline to evaluate the true cost saving impact of the improved industry practice — thus building confidence in the approach.

DNV GL has plenty of first-hand experience of how Joint Industry Projects can be an effective instrument in helping to maturing technology and industry, including in offshore wind. Participation of stakeholders from across the industry (including regulatory bodies) will provide the breadth of perspectives needed for the JIP to establish consensus and allow the early application of knowledge gained with confidence.

Joint Industry Projects Work

DNV GL is a strong advocate of well-targeted and executed Joint Industry Projects and we have already shown that this collaborative approach can work in the offshore wind industry. Our leading role in the recently completed CableRisk project illustrates this.

Problems with subsea cables have affected many offshore wind farms and damage to cables has been identified as a major insurance risk for the offshore wind industry. Cable-related problems are costly and most often arise from inadequate risk identification, lack of planning, sub-standard design and deficiencies in how procedures are applied. To date, cabling failures have cost millions of euros in delays and numerous legal disputes. In order to address these problems, a guideline was developed by the JIP known as 'CableRisk', established in August 2012 by DNV GL and 15 partner organizations, including those listed below.

CableRisk resulted in a subsea power cable guideline: a comprehensive technical guide that covers all project phases of subsea cable projects. It applies to the entire length of the cable and its surroundings including assessment of project conditions, planning and execution of works as well as asset management. Important sections of the 145-page document cover design of the physical interfaces at offshore units and in the landfall area.

Cable Risk Partners

- Bohlen & Doyen
- Boskalis Offshore

- DONG Energy
- Electrabel GDF Suez
- Iberdrola
- Inch Cape (EDPR, Repsol)
- JDR Cable Systems
- Norddeutsche Seekabelwerke
- Offshore Marine Management
- SIEM Offshore Contractors
- Tekmar Energy
- Tideway Offshore Solutions
- Van Oord Offshore Wind Projects
- VSMC

Where Now?

Of the options outlined above, while ambitious, a JIP offers the greatest potential to unlocking the cost-reducing power of an integrated and collaborative approach to design, engineering and procurement in offshore wind. DNV GL welcomes discussions with any interested parties who are keen to explore this.

Ultimately, whichever path our offshore wind industry takes, we believe that healthy levels of collaboration are as important as healthy levels of competition. Whilst we have made significant progress on the latter over the last few years, it is now time that we start acting like a mature industry — embracing both collaboration and integration.

Authors

James Dobbins,
Senior Engineer, Turbine Engineering
James' main area of expertise is wind turbine mechanical systems. During his seven years at DNV GL, he has been involved in eight complete wind turbine design projects for machines with power rating from 1MW to 7MW and has managed two of these projects.
James.dobbin@dnvgl.com

David Quarton,
Senior Technical Advisor, Turbine Engineering
David has over 25 years' experience in the wind energy industry. He led the development of the first international design standard for offshore wind turbines and is a Fellow of the Institution of Mechanical Engineers. He has also participated in the Steering Committee of the European Wind Energy Technology Platform.
David.quarton@dnvgl.com

Paul Reynolds,
Senior Consultant, Offshore Wind, Strategy & Policy
Paul Reynolds is a senior offshore wind consultant at DNV GL. Previously he was Offshore Wind Development Manager at RenewableUK where he co-authored the Cost Reduction Taskforce report.
Paul.reynolds@dnvgl.com

Joe Phillips,
Head of Strategy & Policy
Joe is a Chartered Engineer and Head of Strategy & Policy at DNV GL. His international team provides targeted support to governments and companies. He has worked in renewable energy, primarily in offshore wind, for over 10 years in engineering, project management and strategic roles. He is the lead author on a number of industry reports including "Wind In Our Sails — the coming of Europe's offshore wind energy industry".
Joseph.phillips@dnvgl.com