NOWRDC Webinar -

Opportunities in Offshore Wind Grid Integration

March 19, 2021

Q/A will be managed via the Q/A functionality

NATIONAL OFFSHORE WIND RESEARCH & DEVELOPMENT CONSORTIUM

EPRI ELECTRIC POWER RESEARCH INSTITUTE

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Juergen Pilot

Program Manager,

National Offshore Wind R&D Consortium (NOWRDC)

Fabio Fracaroli

Senior Director,
Renewable Segment
North America,

HITACHI ABB POWER GRIDS

Gary Rackliffe

Vice President
Market and Innovation
North America,

HITACHI ABB POWER GRIDS

Brandon Fitchett

Principal Project Manager

Electric Power Research Institute (EPRI)

Jonathan Ruddy

Senior Project Engineer

Electric Power Research Institute (EPRI) Europe DAC

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National Offshore Wind Research and Development Consortium

Goal: Facilitate a nationally-focused, not-for-profit organization collaborating with industry on prioritized R&D activities to reduce levelized cost of energy (LCOE) of offshore wind in the U.S. and maximize other economic and social benefits

Desired Impacts:

- Innovations directly responsive to the technical and supply chain barriers faced by offshore wind project developers in the U.S.
- Build strong networks connecting technology innovators, investors, and industry
- Increase U.S. content and job opportunities

Project Value: $41 M ($20.5 DOE funds, matched by NYSERDA) – plus state (MA, VA, MD, ME) and member contributions totaling over $7M; 85% of the funds go to R&D projects

Duration: 4 years under current funding (+ 3 years to complete all projects); goal is to become self sustaining indefinitely through research partner funding

Learn more at: www.nationaloffshorewind.org

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NOWRDC Project Awards (3/19/2021)

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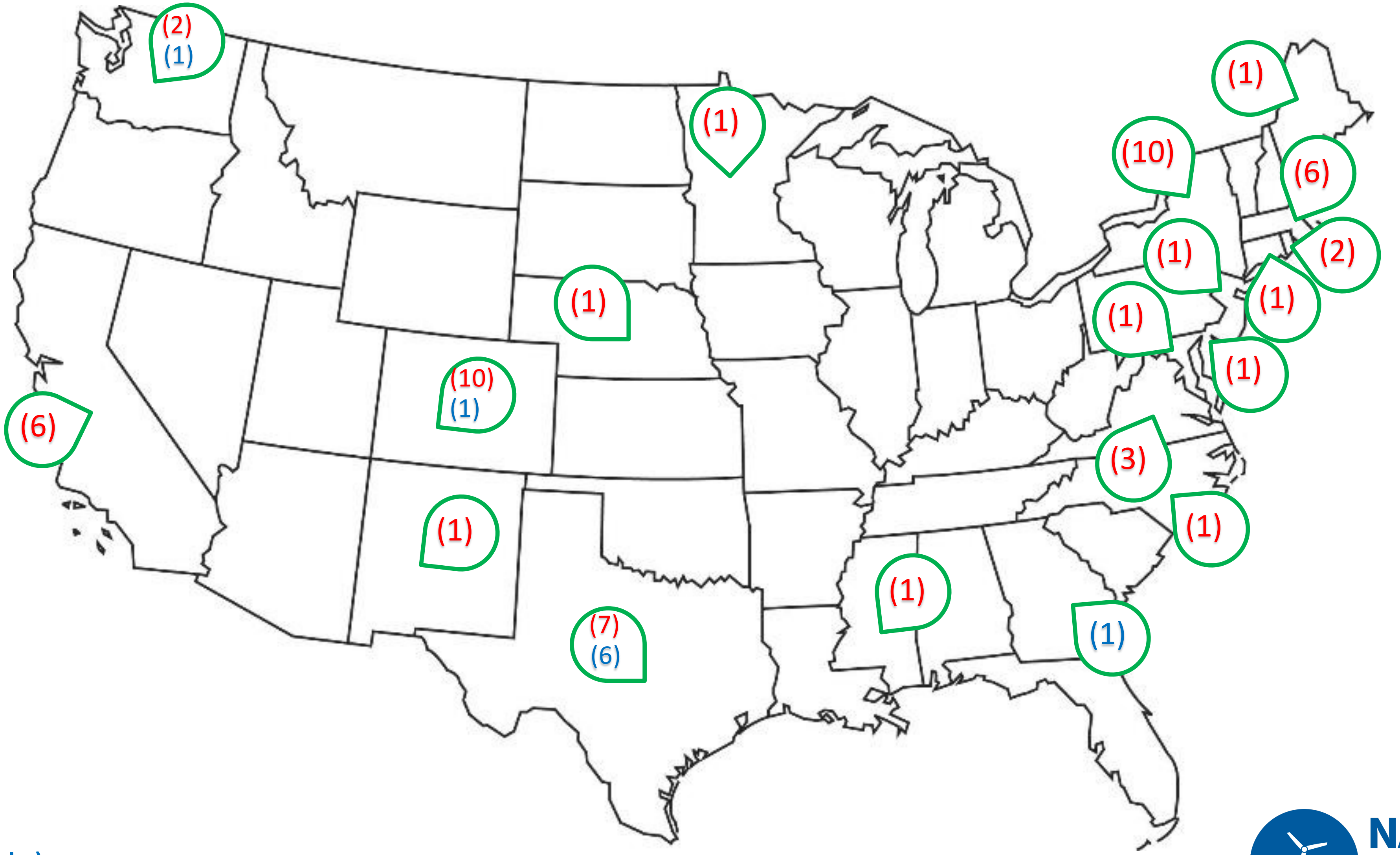
Pillar/Round	Technical Challenge Area	Proposal Title	Lead Proposer	Contract Status	Project Status
PON 4424 Pillar 1: Offshore Wind (OSW) Plant Technology Advancement	1.1: Array Performance and Control Optimization	Computational Control Co-design Approach for Offshore Wind Farm Optimization	Stony Brook University	Executed	Underway
		Impact of Low Level Jets on Atlantic Coast Offshore Wind Farm Performance	General Electric	Executed	Underway
		Reducing LCoE from Offshore Wind by Multiscale Wake Modeling	Cornell University	Executed	Underway
		Wind Farm Control and Layout Optimization for U.S. Offshore Wind Farms	NREL	Executed	Underway
	1.2: Cost-Reducing Turbine Support Structures for the U.S. Market	A Low-Cost Modular Concrete Support Structure and Heavy Left Vessel Alternative	RCAM Technologies	Executed	Underway
	1.3: Floating Structure Mooring Concepts for Shallow and Deep Waters	Demonstration of Shallow-Water Mooring Components for FOWTs (ShallowFloat)	Principle Power, Inc.	In Negotiation	Not Yet Started
		Design and Certification of Taut-synthetic Moorings for Floating Wind Turbines	University of Maine	Executed	Underway
		Dual-Functional Tuned Inerter Damper for Enhanced Semi-Sub Offshore Wind Turbine	Virginia Tech	Under Review	Not Yet Started
		Innovative Anchoring System for Floating Offshore Wind	Triton Systems, Inc.	Executed	Underway
		Innovative Deepwater Mooring Systems for Floating Wind Farms (DeepFarm)	Principle Power, Inc.	Executed	Underway
		Shared Mooring Systems for Deep-Water Floating Wind Farms	NREL	Executed	Underway
		Techno-Economic Mooring Configuration and Design for Floating Offshore Wind	UMass Amherst	In Negotiation	Not Yet Started
	1.4: Power System Design and Innovation Challenge Statement	Development of Advanced Methods for Evaluating Grid Stability Impacts	NREL	In Negotiation	Not Yet Started
PON 4424 Pillar 2: OSW Power Resource and Physical Site Characterization	2.1: Comprehensive Wind Resource Assessment	A Validated National Offshore Wind Resource Dataset with Uncertainty Quantification	NREL	Executed	Underway
	2.2: Development of a Metocean Reference Site	Development of a Metocean Reference Site near the MA & RI Wind Energy Areas	WHOI	Executed	Underway
PON 4424 Pillar 3: Installation, O&M and Supply Chain Solutions	3.2: Offshore Wind Digitization Through Advanced Analytics	Enabling Condition Based Maintenance for Offshore Wind	General Electric	Under Review	Not Yet Started
		Physics Based Digital Twins for Optimal Asset Management	Tufts University	Executed	Underway
		Radar Based Wake Optimization of Offshore Wind Farms	General Electric	Under Review	Not Yet Started
		Survival Modeling for Offshore Wind Prognostics	Tagup, Inc.	Executed	Underway
	3.3: Technology Solutions to Accelerate U.S. Supply Chain	30GW by 2035: Supply Chain Roadmap for Offshore Wind in the US	NREL	Executed	Not Yet Started
PON 4476 Round 1: Enabling Large Scale Turbines	R1C1: Enabling Fabrication and Installation of Future Foundations	Self-Installing Concrete Gravity-Base Substructure Sizing for 15MW Turbine	ESTEYCO SL	In Negotiation	Not Yet Started
		Vibratory-Installed Bucket Foundation for Fixed Foundation Offshore Wind Towers	Texas A&M	In Negotiation	Not Yet Started
	R1C2: Port and Marine Systems Innovation to Support Offshore Logistics	Feasibility of a Jones Act Compliant WTIV Conversion	Exmar Offshore Company	In Negotiation	Not Yet Started
		Tech. Validation of Existing US Barges as a Feeder Solution for US Offshore Wind	Crowley Maritime	In Negotiation	Not Yet Started
		Comparative Operability of Floating Feeder Solutions	MARIN USA	In Negotiatiojn	Not Yet Started

*Awards under negotiation remain tentative pending contract execution

NOWRDC Solicitation Recipients (Prime and Subrecipients 3/19/2021)



PON4424

PON4476 (R1 Only)

*Non-US entities not shown

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Agenda

1. **US Market for Offshore Wind & Grids Evolution – Fabio Fracaroli**
2. Offshore Generation Technologies – Brandon Fitchett
3. Offshore Grid Technologies – Jonathan Ruddy
4. Grid Integration – Gary Rackliffe
5. Conclusions and takeaways

US Market for Offshore Wind

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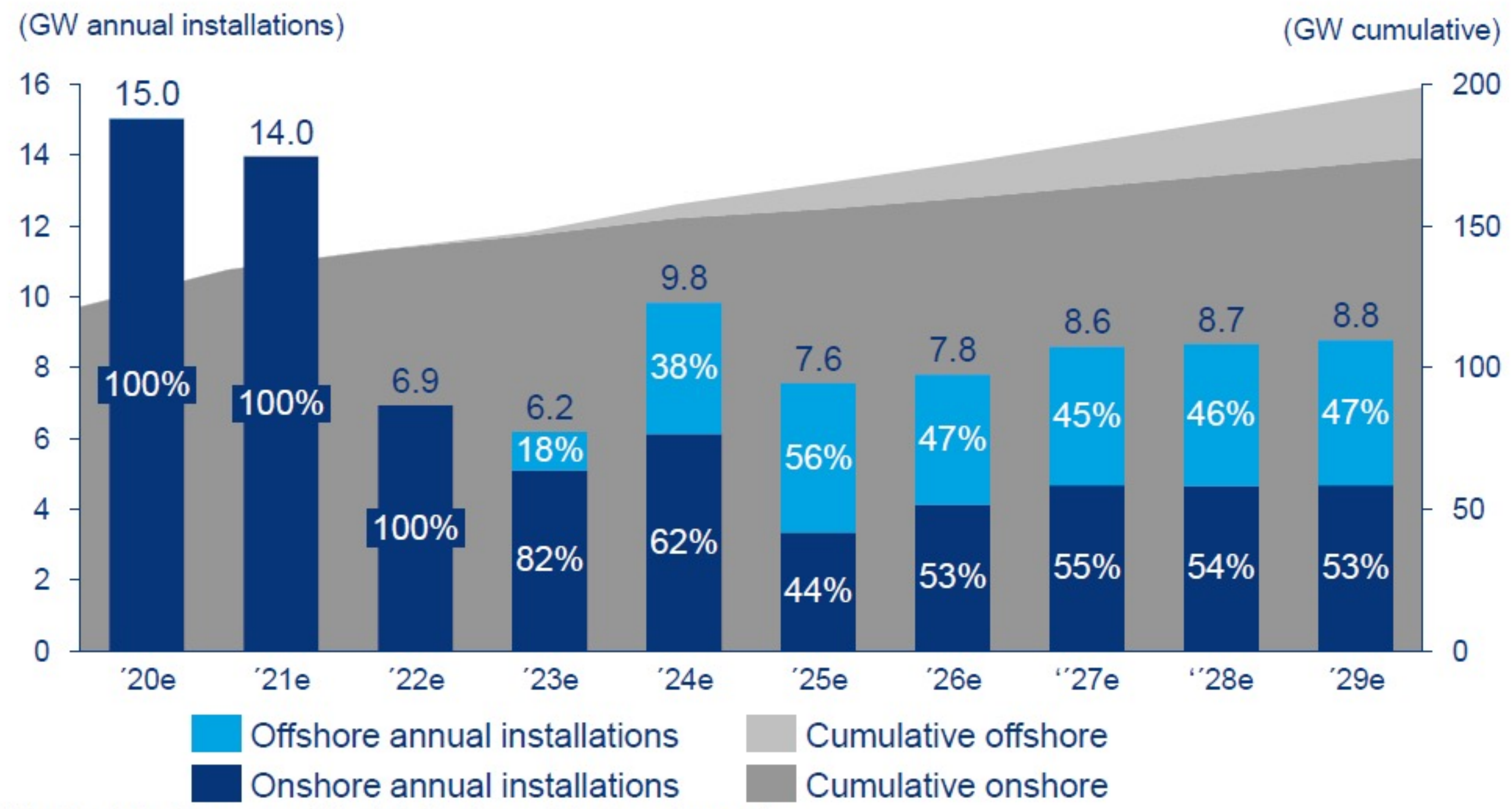
Executive Summary

- Fundamentals in place: natural resources, decreasing costs, location, public and corporative support, government support
- US Offshore Wind industry targeting +30GW by 2035 (East Coast only), with upside growth opportunities under new incentives e.g., Investment Tax Credits (ITCs) supporting lower generations costs of energy (LCOE) and longer development time frame
- US as one of the most attractive markets (EU players, O&G majors, Utilities, Government, Public support, Economic recovery)
- State level support, with existing uncertainties and expectations to overcome initial hurdles, particularly on Federal permitting processes
- The pace of growth will test US operators' ability to accommodate new generation and will challenge transmission grids

U.S. onshore and offshore wind grid-connected forecast, 2020-2029



Note: Cumulative figures are net, thus including decommissioning and repowering

Source: Wood Mackenzie

Grid systems of the future – an evolutionary vision

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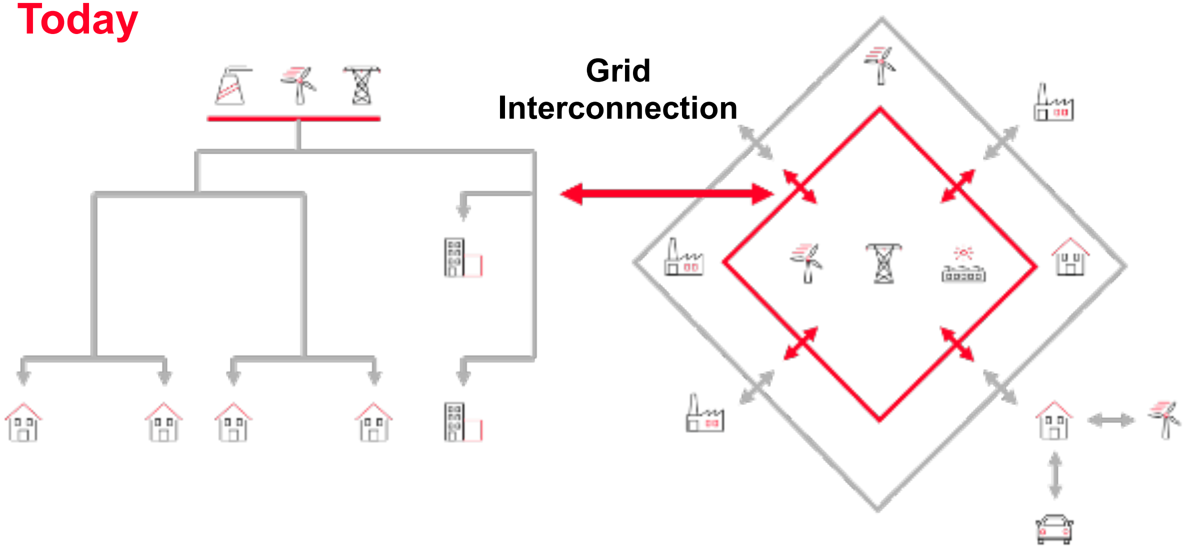
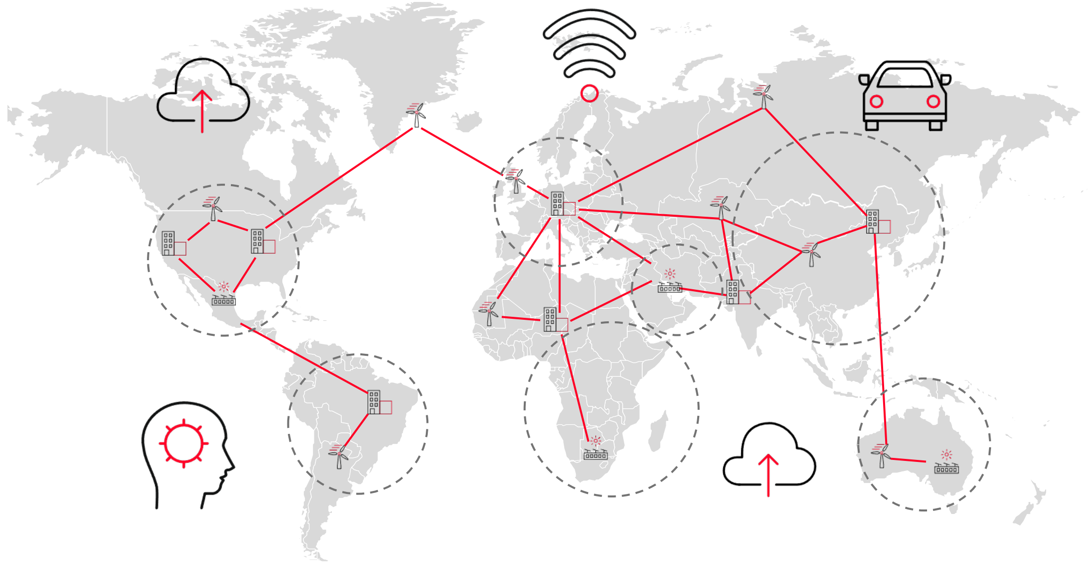
Today



Tomorrow



Factors:

- Full scale deployment of renewables across all regions
- Increased share of energy by wire and distributed energy resources
- Massive introduction of grid connected electrical vehicles
- Decarbonization, decentralization, bi-directional flows

- Utilities adjusting to new, additional business model
- Fully flexible power exchange with related data transfer ("Internet of Energy")
- Real-time control and higher security
- Artificial Intelligence enabling complex autonomous processes

Grids of the future demand flexibility, resilience, intelligence and interconnectivity

Offshore wind and grids geared to play a major role in the energy transition

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Decarbonization and electrification
need acceleration of growth of renewables

Renewables cost reduction secures
affordable clean energy

Projections indicate **150 GW installed capacity by 2030***

$840B* estimated to be invested over the next 2 decades

Transmission accounts for
~25% of CAPEX today

Large **high-capacity factor** farms can be built relatively **close to coastal load centers**

Lower hour by hour variability
than onshore wind

Offshore wind **seasonally complementary to solar**

Can be used to
produce green hydrogen

Energy transition has to secure
local job creation and economic growth

Sustainable generation

* Globally

Players in the offshore wind industry face constant new challenges

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- Digitalization, interoperability, cybersecurity
- Role of storage and PowerToX
- Bankability, entry into new markets, asset management
- Optimal system design
- **Grid development and integration**
- Performance, energy efficiency, reliability, availability
- PPA's, subsidy free renewables, merchant projects, new revenues
- LCOE reduction (larger turbine, higher voltage, larger wind farms, minimize total cost of ownership, speed…)

Technology is developing fast to enable sustainable growth of the segment

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Larger turbines under development – **today +12 MW**

Higher voltage – 66 kV as new standard for offshore wind farm array

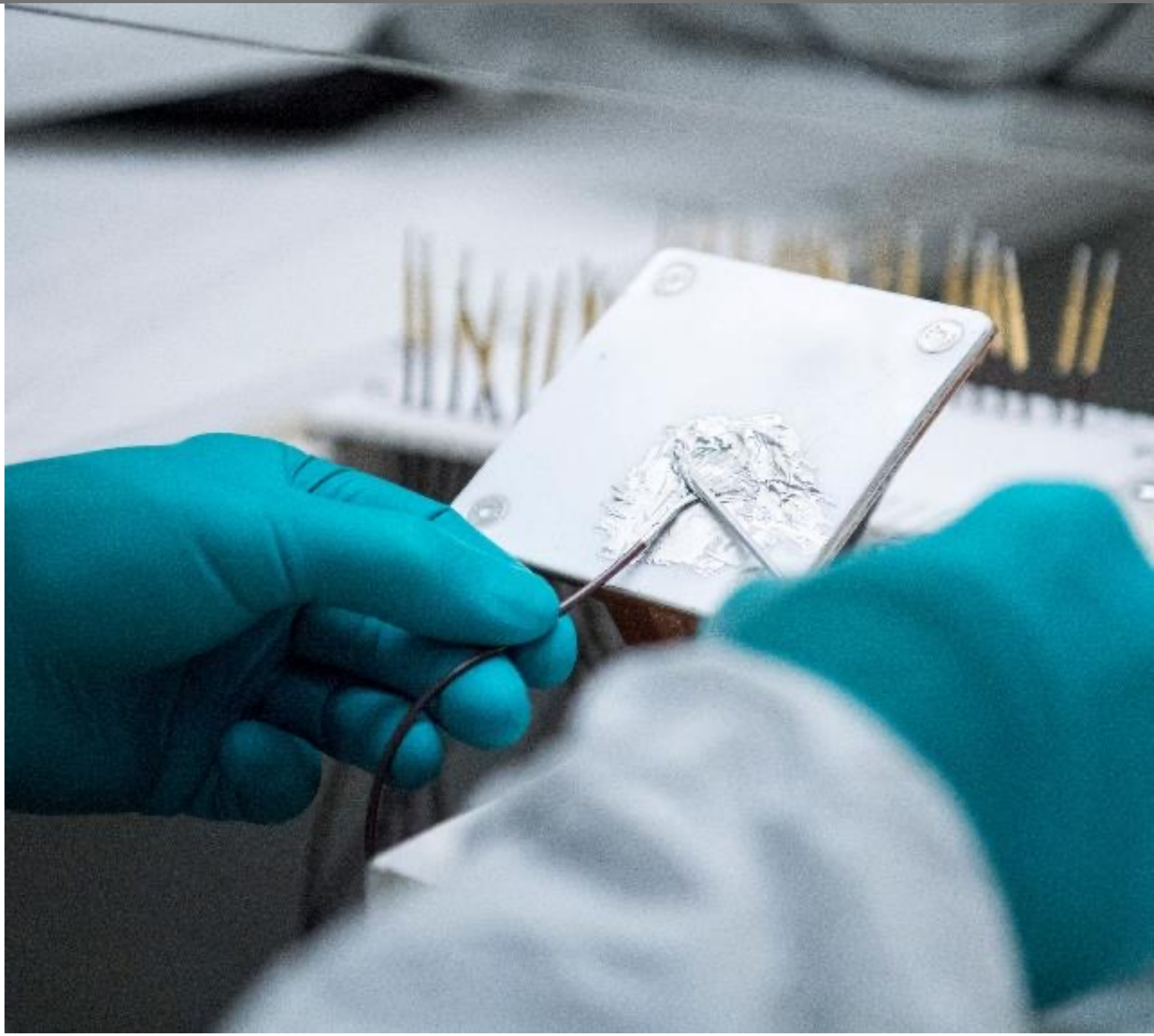
Digitalization – for better asset utilization and integration of offshore wind to the grid

HVDC – to connect larger wind farms further away from the shore. HVDC also supports system stability

Floating offshore – to unlock further offshore wind potential

Energy storage – for **grid stabilization** and to provide ancillary services

Meshed grids – the future offshore infrastructure stability



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Mission

Values

- > $400M annual funding, 1/3 international (> 450 participants in 38 countries)
- Technical Staff: 1000 employees
- Dozens of programs across Power Generation (non-Nuclear); Nuclear Power; Transmission and Distribution; Integrated Grid; Electrification and Sustainability; Technology Innovation.

Future Wind Power Plants

EPRI Wind Power Plant R&D Program

For a *reliable, affordable, resilient, and sustainable* electricity system, Wind Power Plants will need:

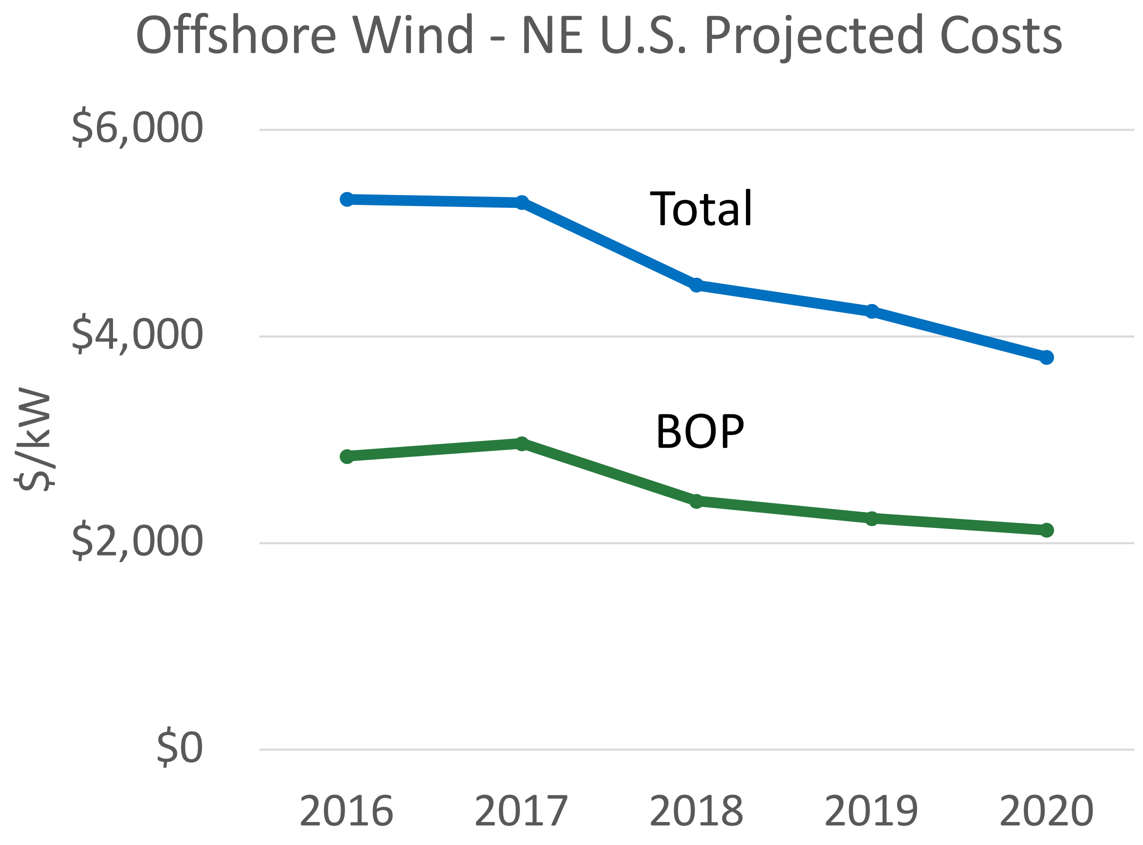
Improved Lifetime Energy Production

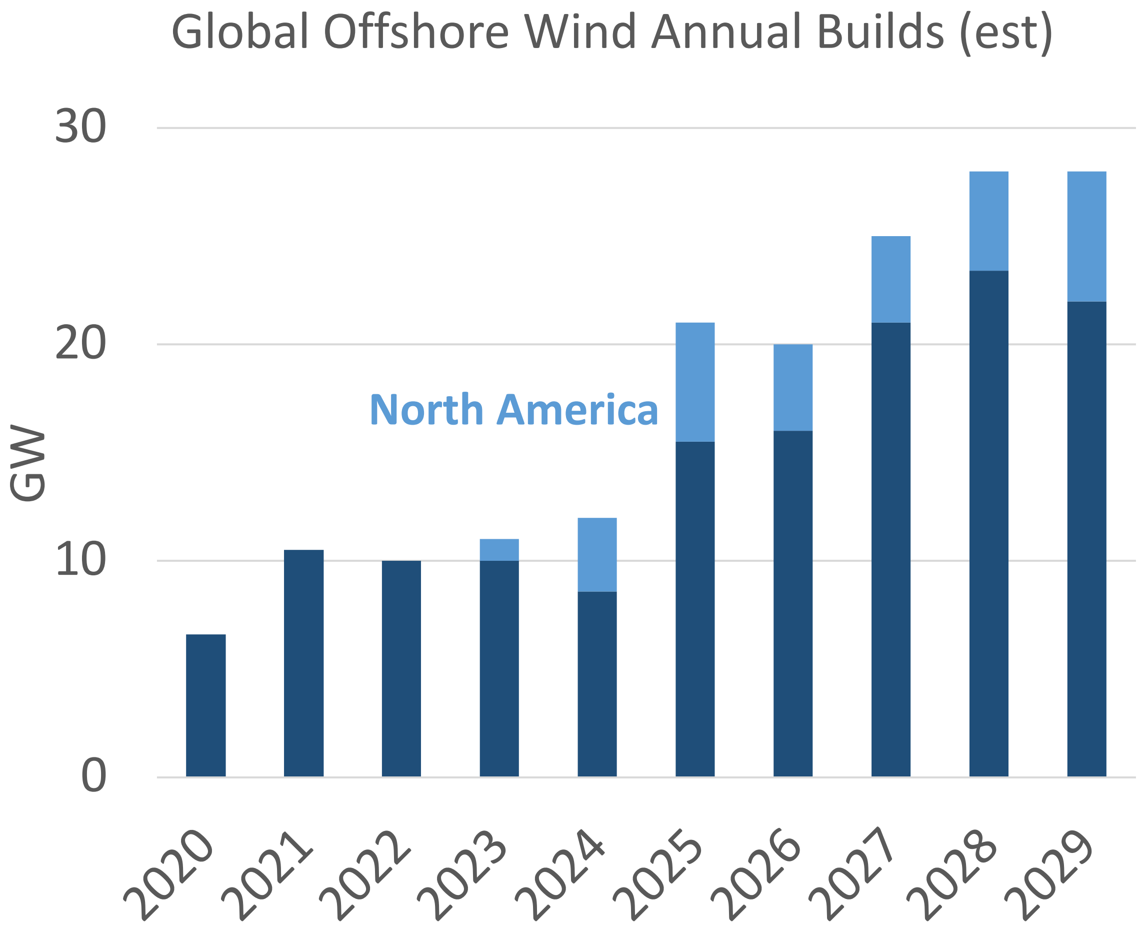
Reduced Costs, Capital & Operational

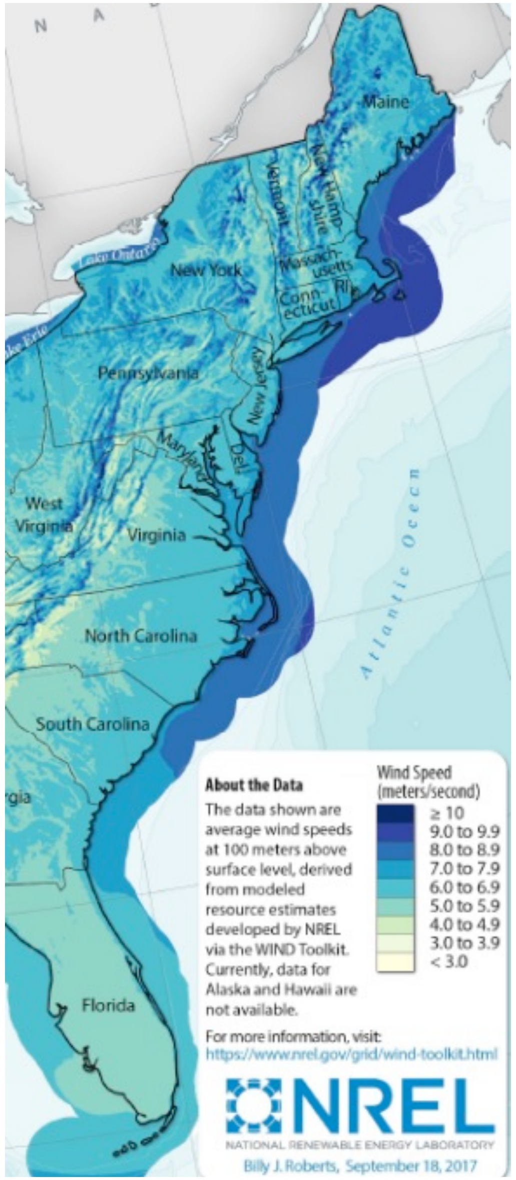
Increased Dispatchability and Grid Services

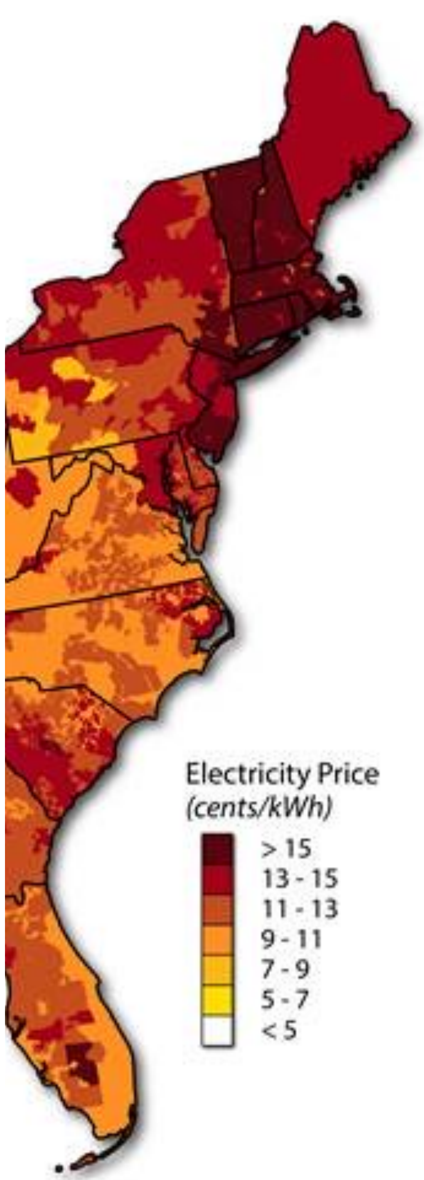
Increased Sustainability

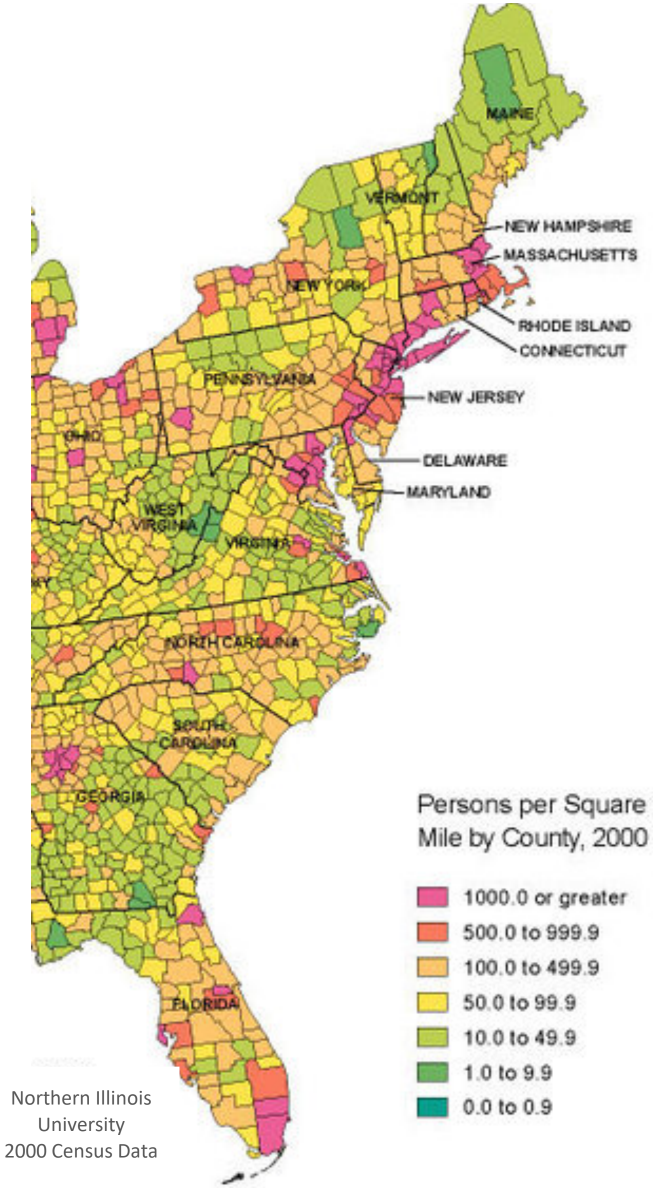
Deployment to Increase as Costs Decrease



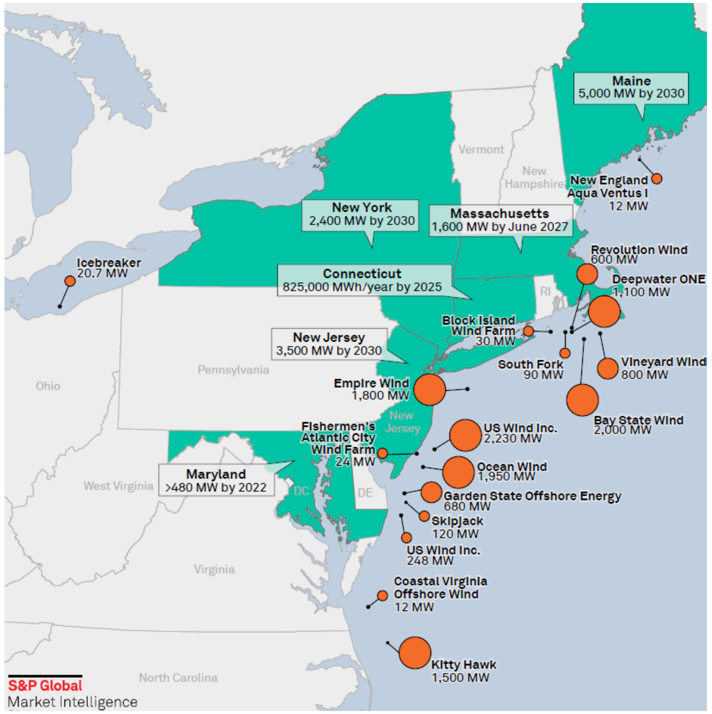






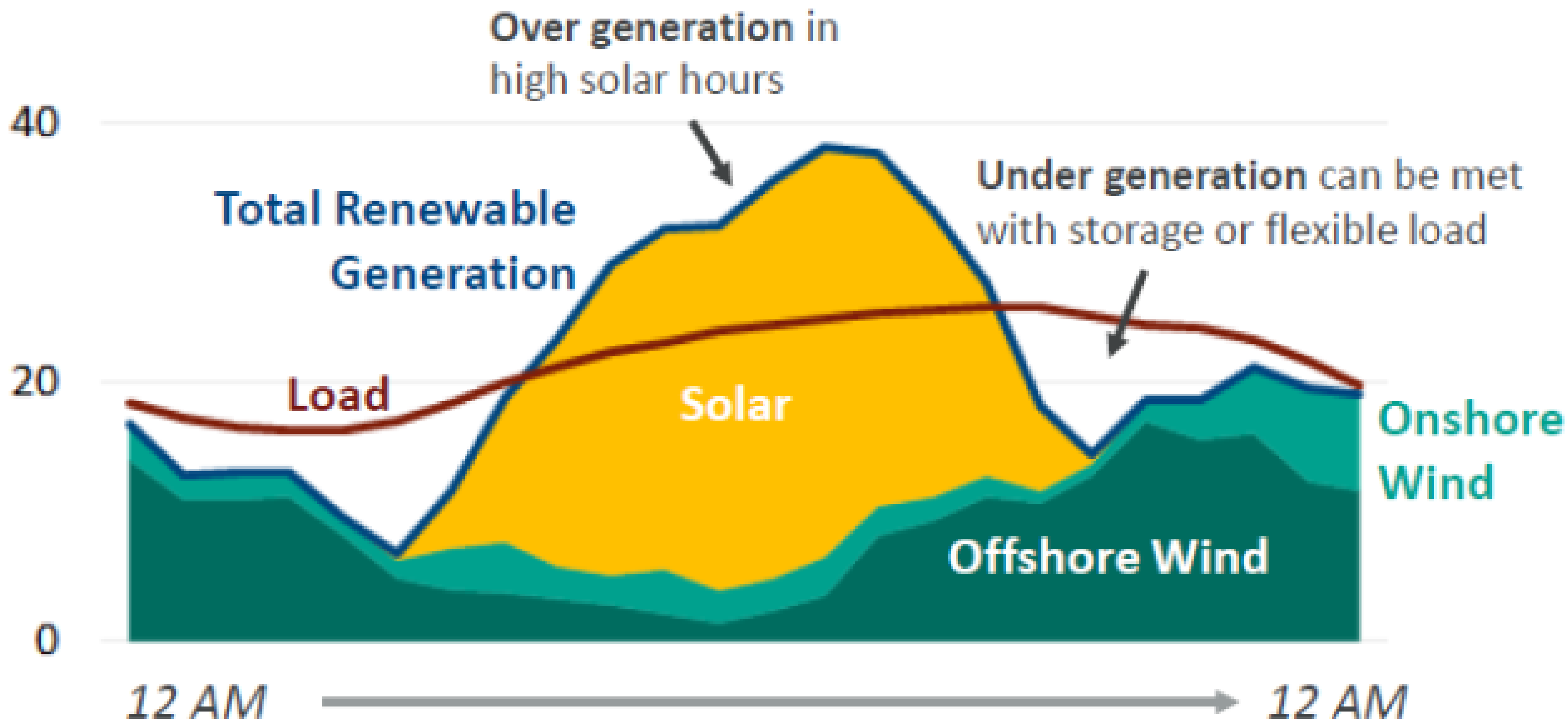


Northern Illinois University
2000 Census Data



Resource, Water Depth, Electricity Price, and Load Proximity

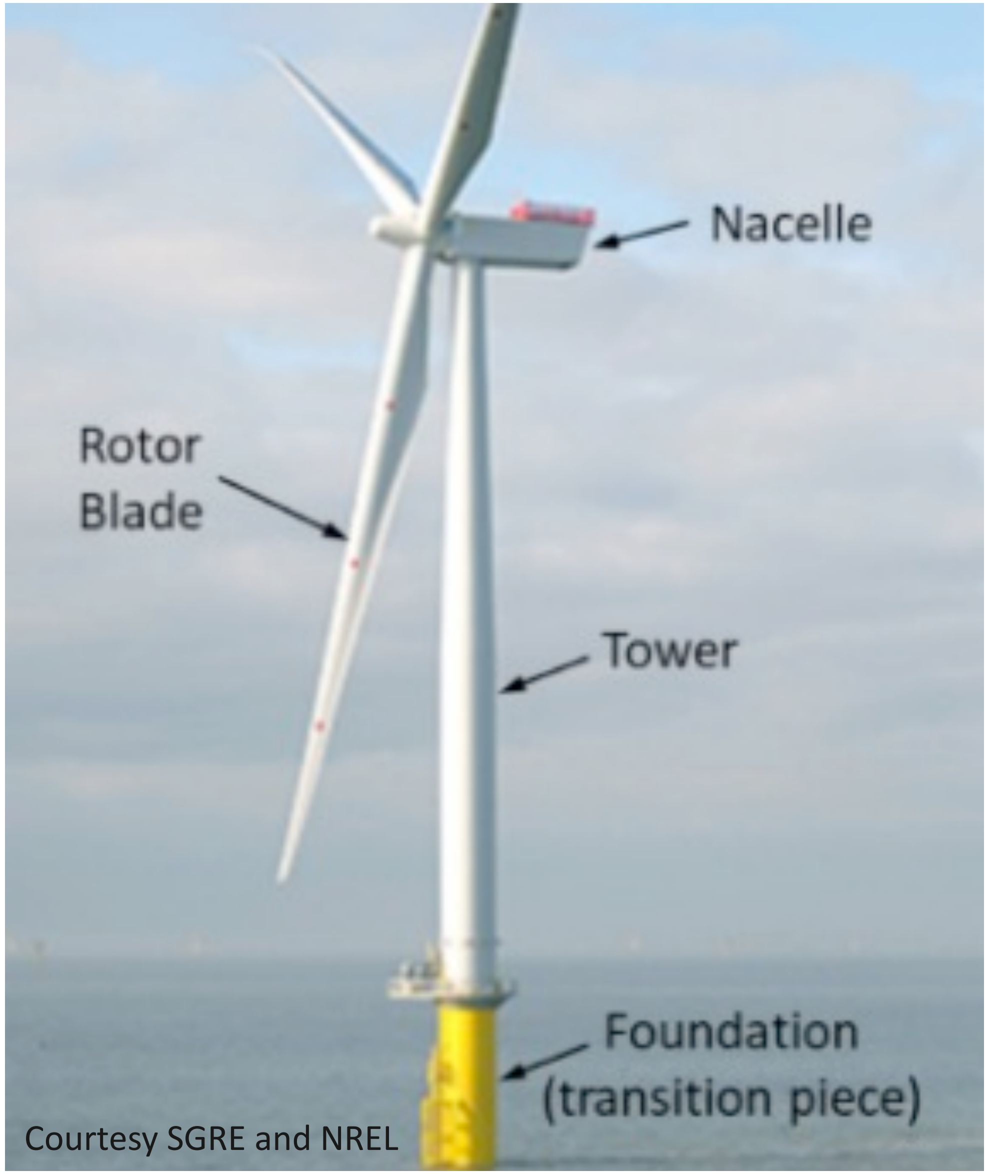
NY/NJ Example

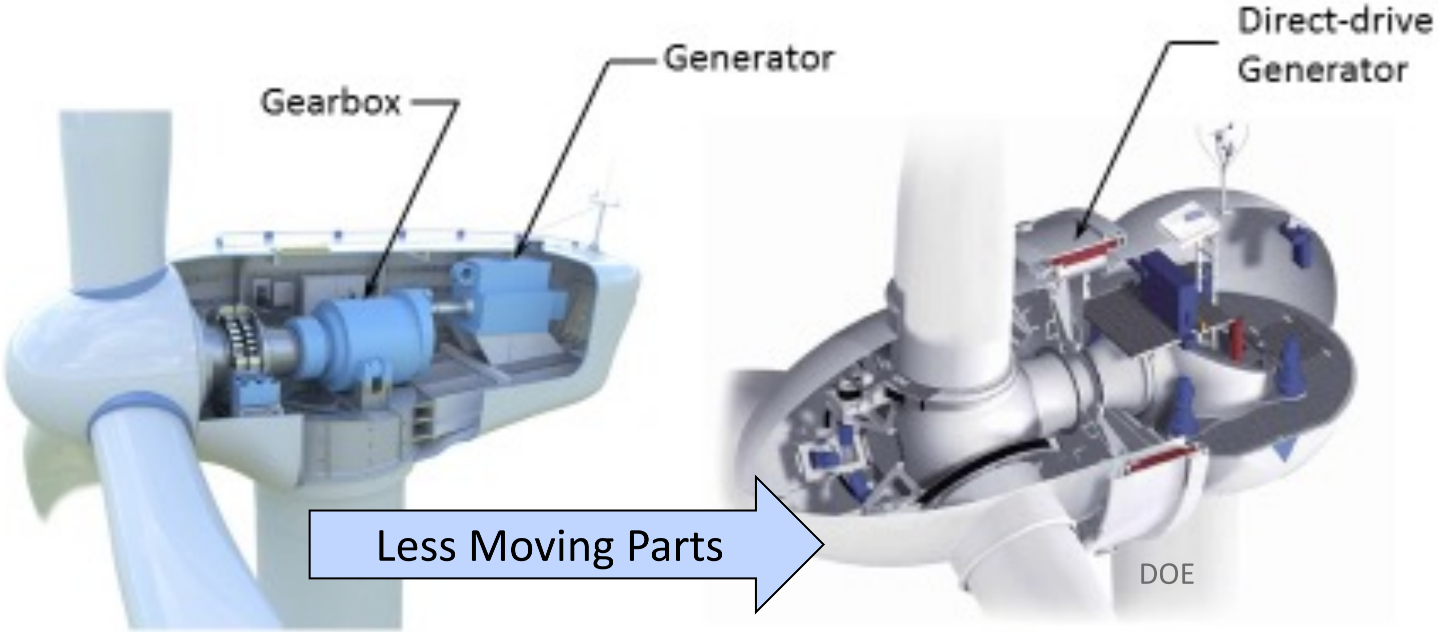


From: Brattle NYISO Electric Grid Evolution Study 2020 - LINK

Challenge: Energy When You Need It

Offshore Wind Farm Technology Basics – Turbine

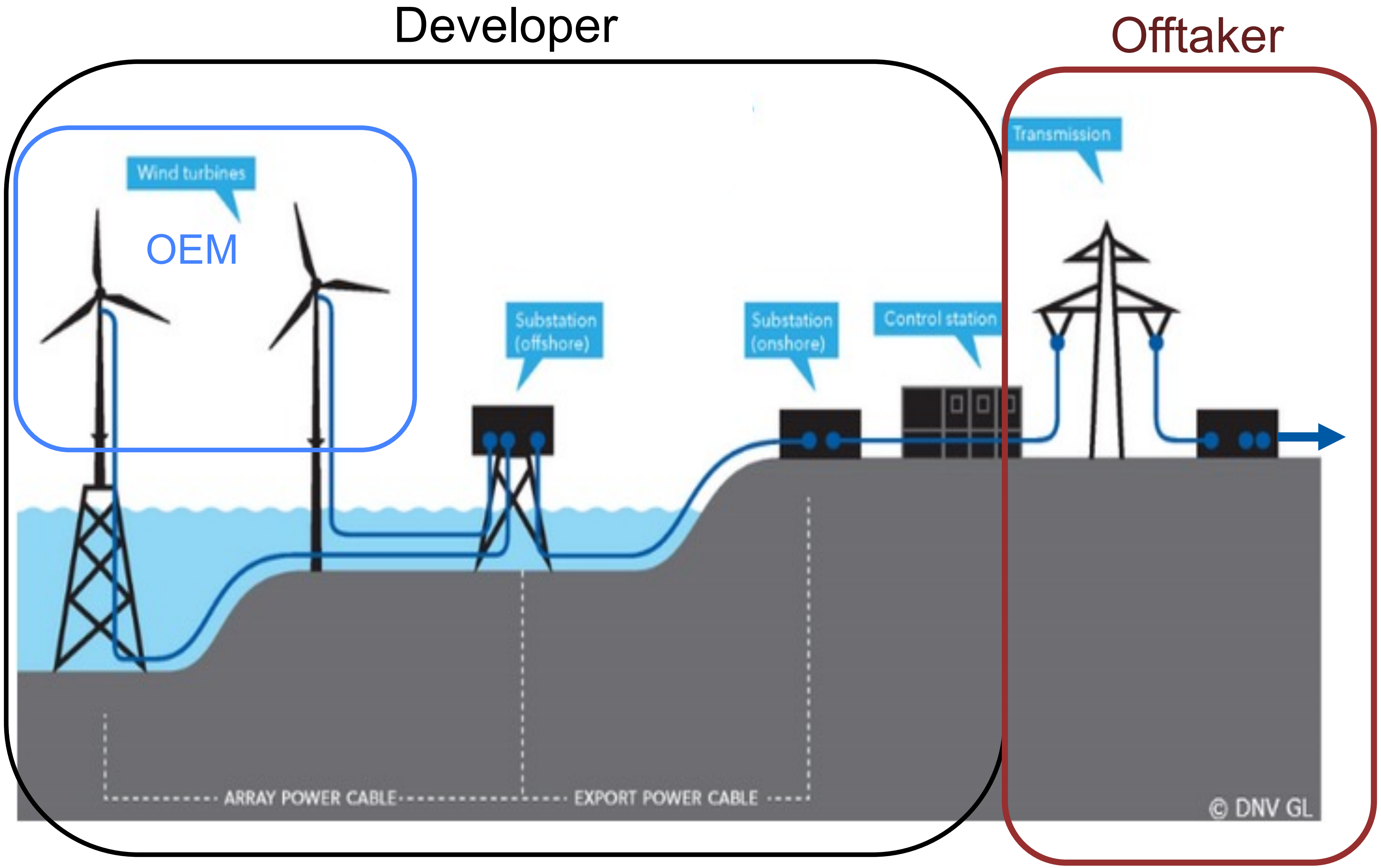




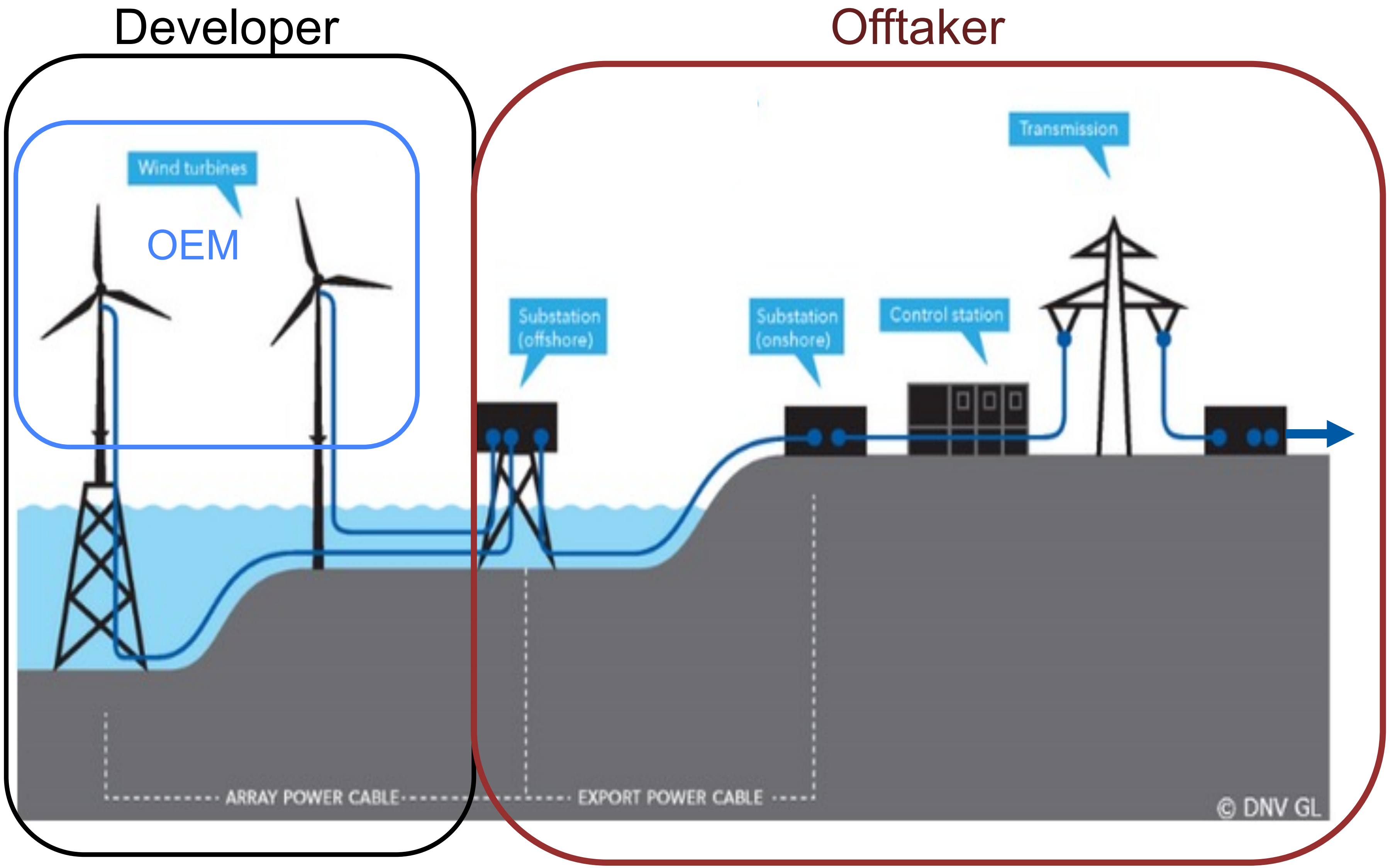
- >10 MW, >200m main rotor, 8 RPM
- Power production 4-25m/s (12-25m/s full pwr)
  - -20 or -30C to +35-40C
- Sustain gusts up to 70m/s (Class 3-4 hurricane)

Integration Challenge – Operation at the Extremes

Offshore Wind Scopes and Parties – U.S. Typical

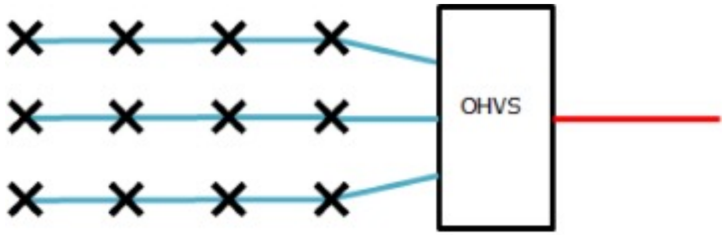


Offshore Wind Scopes and Parties – Europe Typical

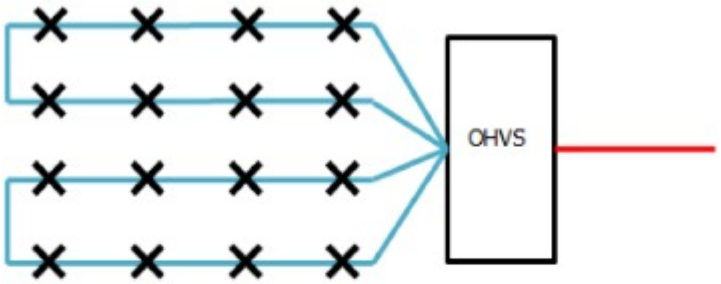


Electrical BoP options

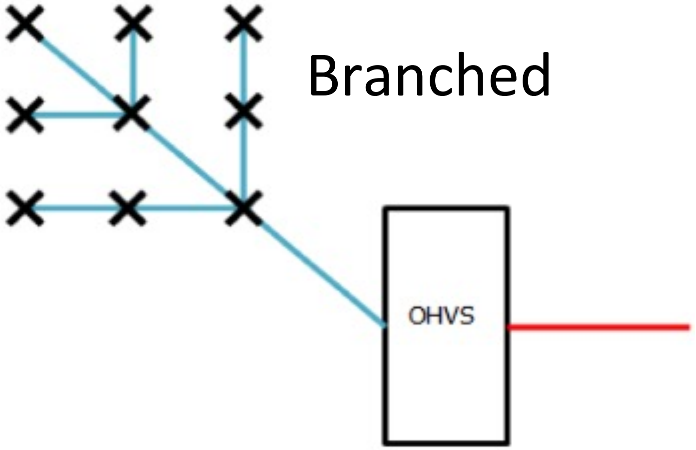
Radial



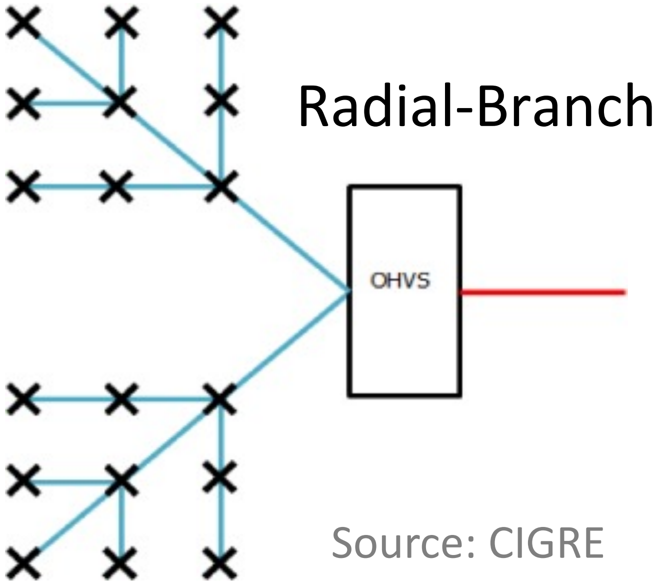
Closed Loop



Branched



Radial-Branched



Source: CIGRE

Challenge: System Optimization with Turbines, Transmission, and Integration

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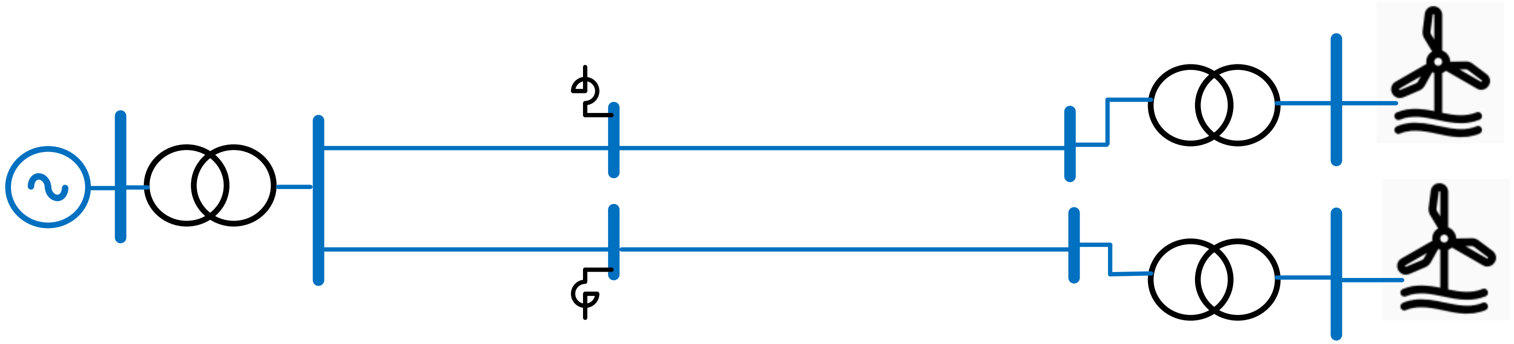
Traditional Transmission Connection Methods for Offshore Wind

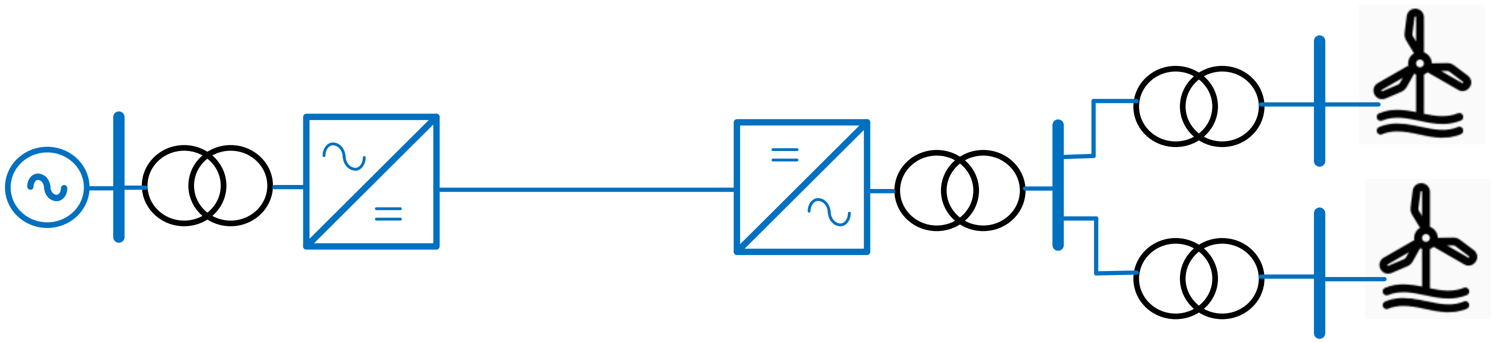
HVAC Interconnection

- HVAC cables
- Near-shore
- Capacitive charging current in subsea cable limits transmission distance
- Significant reactive compensation required



HVDC Interconnection

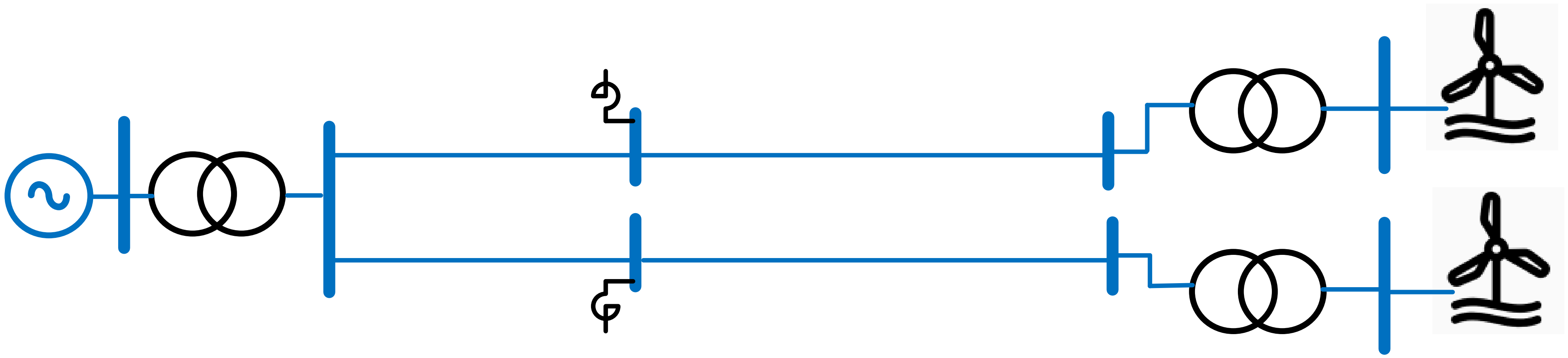
- Far offshore
- DC cables
- VSC HVDC Converter stations on and offshore



HVAC Connection

- Mid Point reactive compensation may be required if long distance to shore
- Onshore - reactive compensation (SVC/STATCOM) may be required to meet grid code voltage requirements
  - Synchronous condensers?
- Offshore reactive compensation
- Standardisation of HVAC offshore technology helps modular build out

Need to understand:
- Control resonance and stability
- Harmonic mitigation
- Voltage control & regulation
- Transient voltages
- Protection
- Coordinated control of parallel plants
- Implications of long HVAC cables on system operations

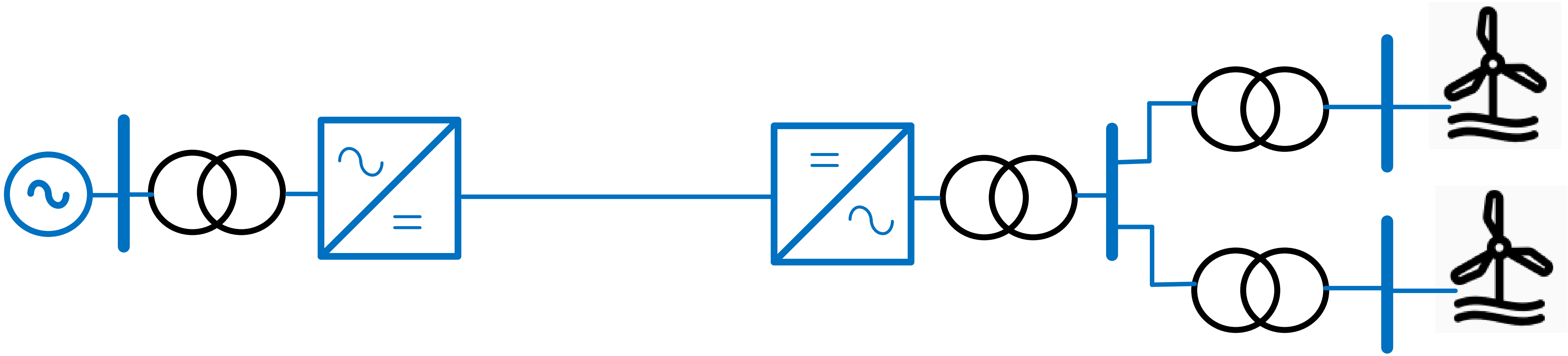


HVDC Connection

- Point to point DC connections "well understood" in 2021
- Independent control of reactive power
- Parallel HVDC links from offshore more complex

Need to understand:

- Stability in offshore network
- 100 % inverter offshore collection network
- Grid Forming offshore
- Multiple HVDC connected Wind Plants
- Control of parallel HVDC
- Interoperability of vendors



Meshed Offshore Grids - Step by Step

Existing experience – AC and DC connections

» Parallel AC connections with interlink

» Parallel DC connections with AC interlink

Next steps

<u>Hybrid interconnectors</u>

<u>Parallel connected existing AC and new HVDC</u>

» Offshore wind plants still synchronously connected to onshore network

<u>Multi terminal HVDC</u>

» Interoperability is important

NGESO – Offshore coordination study – integrated approach

Cost Savings

18% beginning 2025
9% beginning 2030

Environmental Benefit

Landing points reduced 50%
386 vs. 173

Onshore Infrastructure

Integrated approach minimize onshore grid upgrades

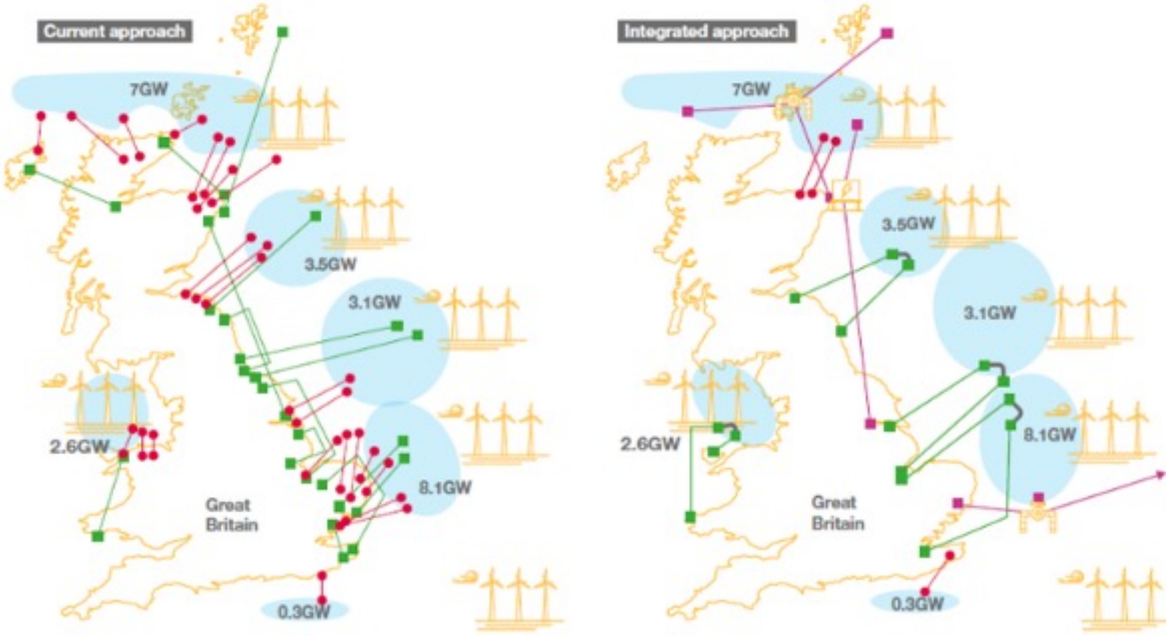


Image Credit: NGESO via DNV et al

Study: https://www.nationalgrideso.com/future-energy/projects/offshore-coordination-project

US context

- Coordinated onshore/offshore long term grid development
  - HV grid infrastructure not near shore
  - Use of infrastructure?
  - Max infeed?
  - Impact of neighbouring states targets on Planning & Ops
  - Coordination of synchronous plant retirements and offshore wind connections?

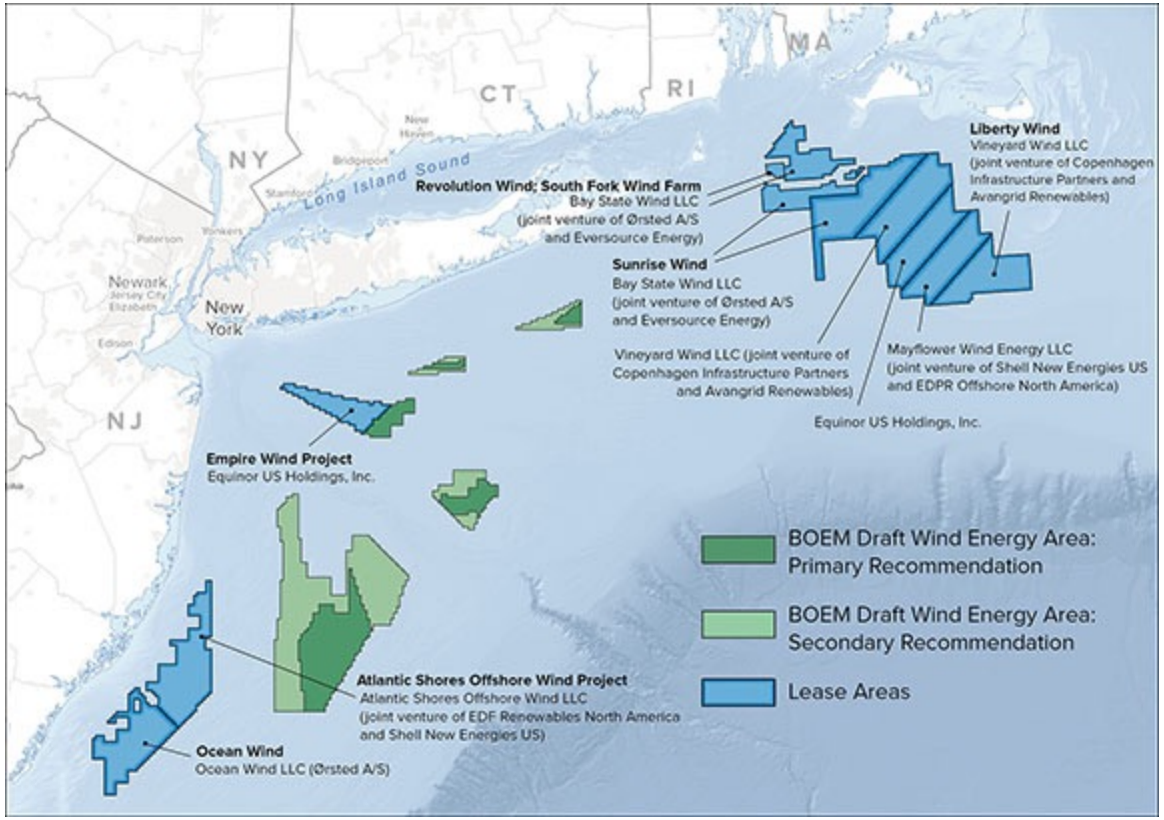


Image Credit: NYSERDA

What does the grid look like with high penetrations of offshore wind?

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Renewables: fundamentally new challenges for power systems

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Variable generation profile

- Maximum output varies depending on wind and sunlight
- No perfect forecast available for wind and sunlight
- Most of the renewable energies have little to none base load capability

Location constrained

- Areas with the best resources are often situated in remote locations. Tapping into these resources will require efficient ways to transport a large amount of power over long distances

Inertial response capability

- Wind and solar installations are non-synchronous generation technologies that connect to grid via power electronics and have little or no inertial response capability

Modularity and distributed

- More production entities dispersed along the power system
- Increasing levels of distributed generation will require new approaches to regulate and manage the energy production and the power system

Renewable energies are the key drivers in the evolution of the power system

Technologies across sectors and drivers

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Drivers	System operation	Generation	Transmission	Distribution	Usage	Market
Variability and uncertainty	– Production forecasting – Demand Response – Wide area monitoring – Virtual Power Plants	– Production forecasting – Generation management system – Virtual power plants	– Grid expansions – HVDC – Bulk energy storage – Automation and control	– Distributed storage – Load forecasting – Renewable production forecasting	– Energy storage – Home and building automation	– Energy Portfolio Management – Market Management System
Lack of inertial response capability	– Synthetic inertia control – Frequency control – Plant and fleet automation and control	– Plant automation and control – Energy storage	– Energy storage	– Flywheels – Energy storage	– Energy storage – Demand response	– Ancillary services definition
Locational constraints	– Grid expansions – FACTS – Energy storage – Line voltage regulator – Online tap changers		– FACTS – Long dist. transmission – HVDC	– Regional micro grids – Grid interties – Line voltage regulator – Online tap changers	– Nano grids	– Nodal price forecast
Modular & distributed	– Grid automation – Volt/ VAr management – Virtual Power Plants			– Grid automation – Volt/ VAr Management	– Virtual Power Plants	– Virtual Power Plans

Communication and Cyber Security

Services and Asset Management

Consulting

Location constrained: What it means for the grid?

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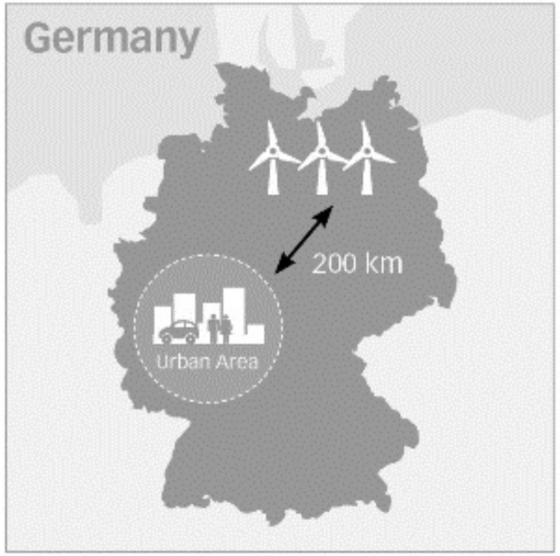
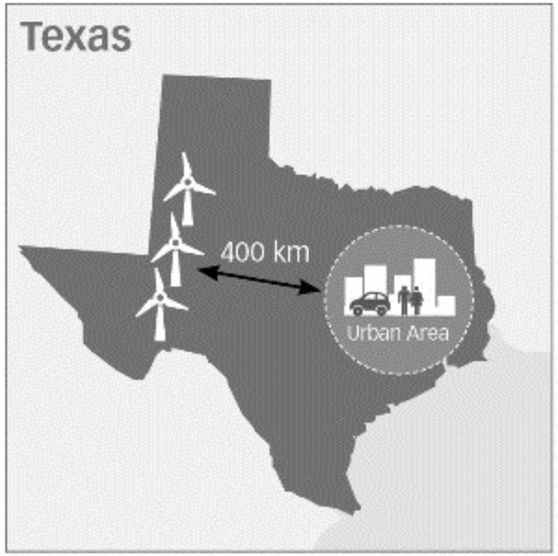
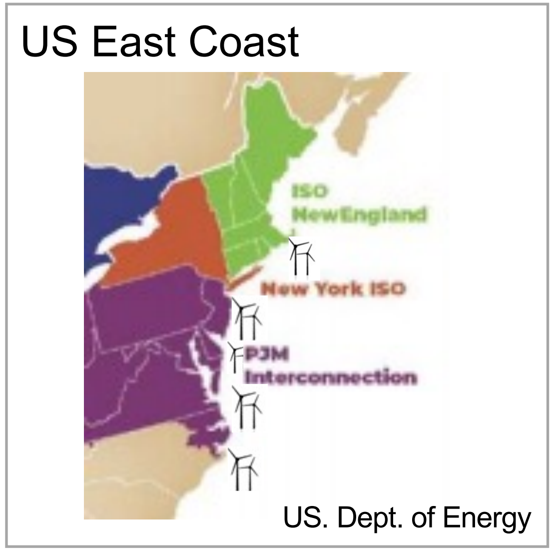
- Renewable energies need wide areas to catch the natural available resources
- This areas are usually not close to consumption centers
- The generated energy needs to be transported to the load centers, stored for later use, or curtailed.
- Along the East Coast, the location challenge is the transmission congestion in SE Massachusetts, NY, and NJ.







Comparison of some regional characteristics: Germany, Texas, and U.S. East Coast

The location of renewable plants requires a smarter grid to facilitate their proper integration

Inertia response capability: What it means for the grid?

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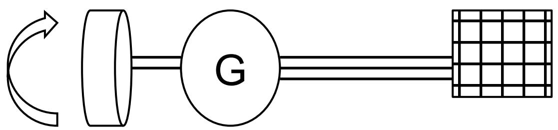
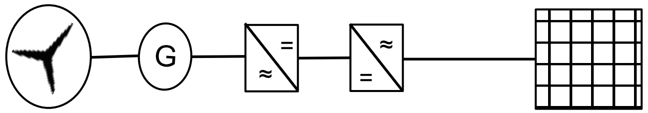
- Non-synchronous generation like solar and frequency variable wind generators with power electronics are the fastest growing generation resources.
- These resources lack a generator rotor or rotating mass that can support grid frequency response by providing inertia to the grid.
- Usual frequency control systems in the grid rely on the inertial response for primary frequency control

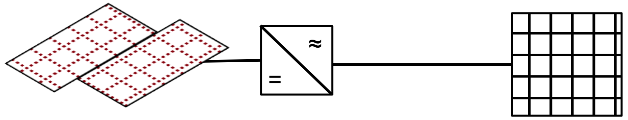
Conventional power plants



Wind Power



Solar PV



With less rotatory mass frequency stability and control become more challenging

Transmission technologies

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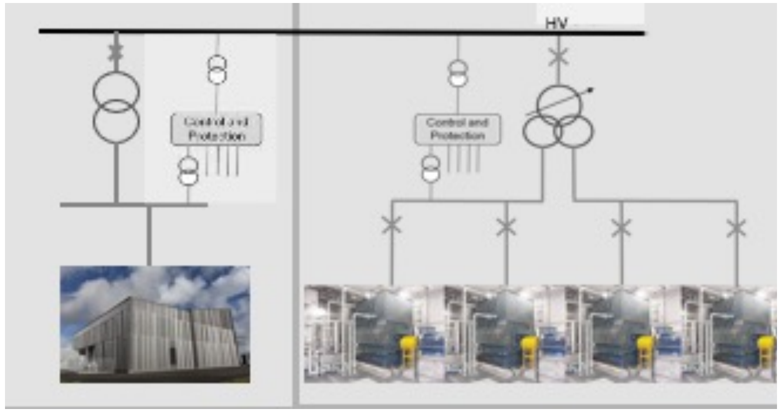
Offshore Platform

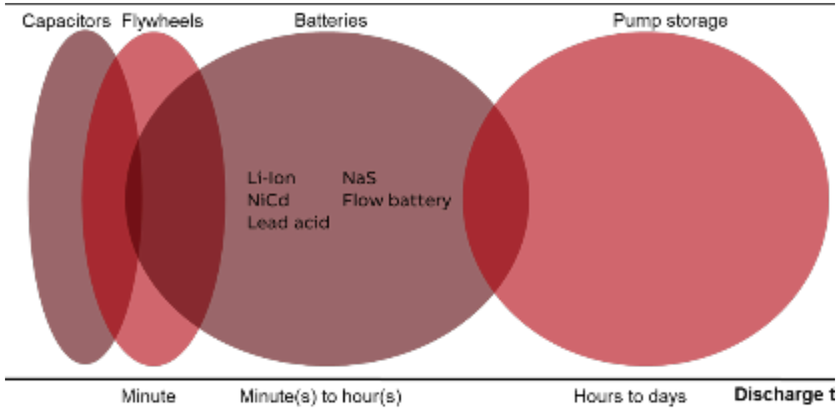
HVDC Transmission

Series Capacitors

SVCs/STATCOMs



STATCOM and Synchronous Condenser



Energy Storage

HVAC or HVDC?

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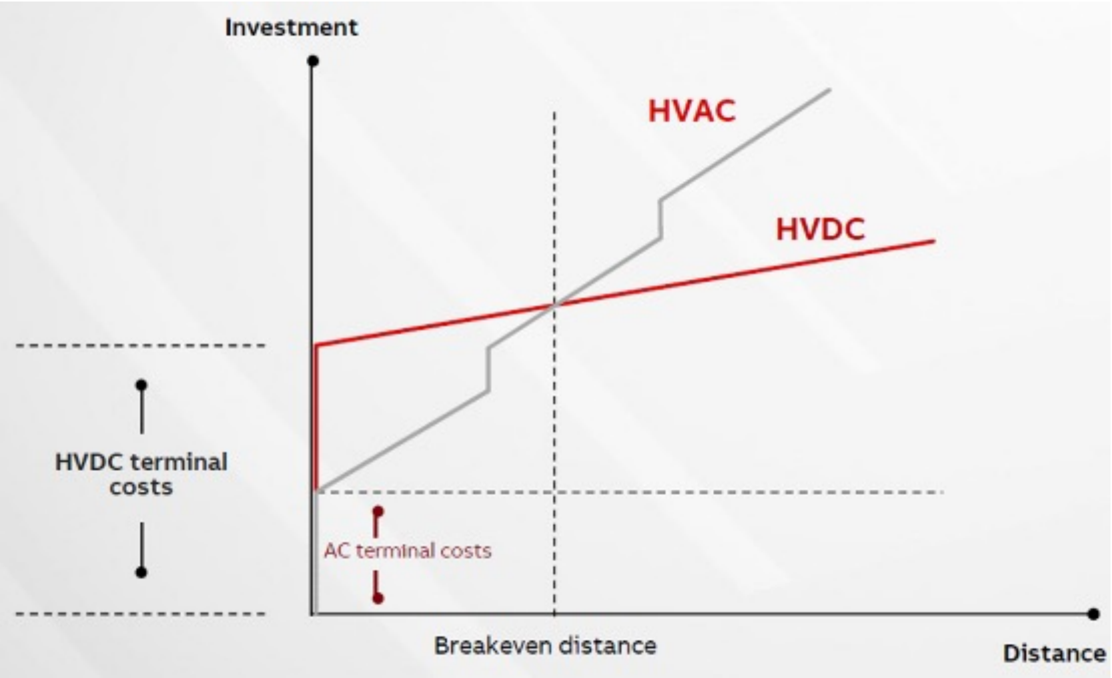
HVAC

- + Well known and proven technology
- + Shorter deliver time
- + Moderate sized offshore platforms => Larger supply base
- + Lower initial costs
- – Limitation in maximum cable length due to high charging currents
- – Long distances may require mid point compensation
- – Typically higher losses
- – Many cables => Possible capacity issues on supply side
- – Cable installation
- – May require Statcoms to fulfill Grid Code Requirements



HVDC

- + Well known and proven technology
- + Superior dynamic behavior and features
- + Onshore and offshore grid support e.g. AC voltage and frequency stabilization
- + Black start capability
- + No minimum short-circuit power requirement for weak AC networks
- + Inherent Statcom functionality
- + Less cables and typically lower losses
- + No limitation in distance
- – Large offshore platforms
- – Longer lead time than AC
- – Less cost efficient if short distance and/or low power rating

Southeast Massachusetts (SEMA) transmission

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ANALYTICAL APPROACH

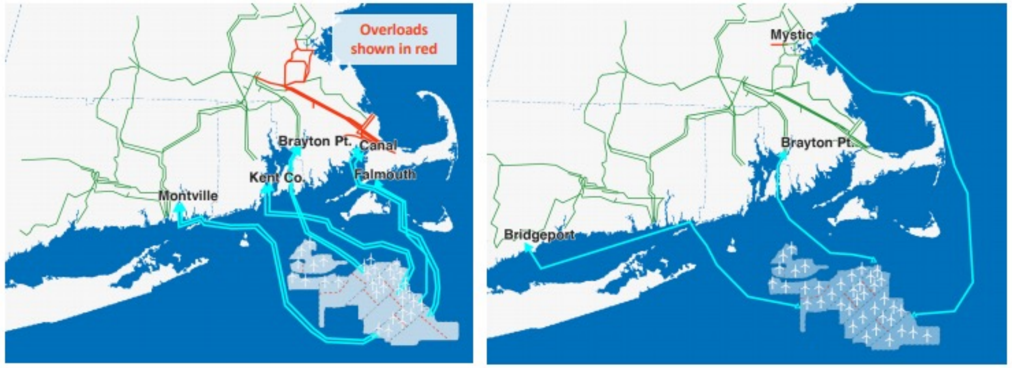
Phase 1 (add 3,600 MW): Summary of the two transmission approaches

Current GLL Approach

- 9 x 400 MW High Voltage Alternating Current (HVAC) cable bundles:
  - 800 MW each at Montville, Kent Co. Brayton Pt. & Canal
  - 400 MW at Falmouth
- 694 miles of marine cabling
- 4.0% losses
- Significant onshore transmission overloads

Planned Offshore-Grid Approach

- 3 x 1,200 MW High Voltage Direct Current (HVDC) cable bundles
  - 1,200 MW each at Bridgeport, Brayton Pt. & Mystic
- 356 miles of marine cabling
- 2.4% losses
- Minimal onshore transmission overloads



Sources: Overloads based on GE analysis for Anbaric (Appendix B), which identified numerous within-zone overloads not identified in ISO-NE zonal analysis. Loss estimates based on vendor specifications and third-party sources

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ANALYTICAL APPROACH

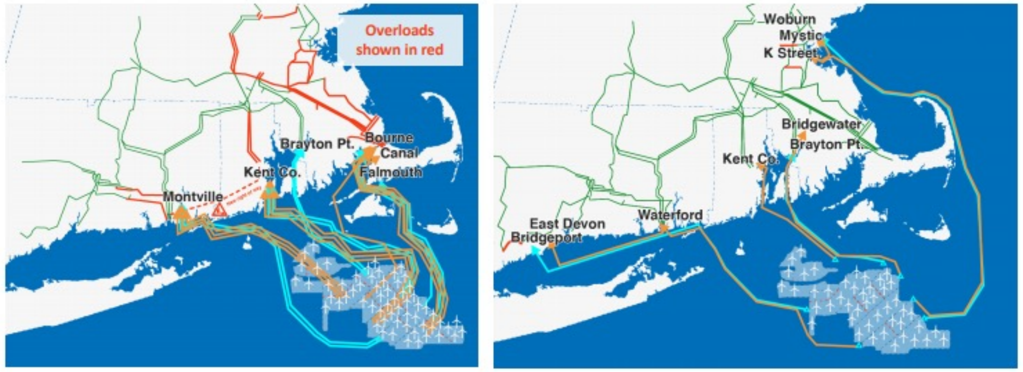
Phase 2 (add 8,000+ MW): Summary of the two transmission approaches

Phase 2, Current Approach (add 8,200 MW)

- 9 x 466 MW HVAC cable bundles
  - 1,400 MW each at Montville, Kent Co., & Canal
- 1 x 400 MW HVAC project
  - 400 MW at Bourne
- 926 miles of marine cabling *(1,620 through Phase 2)*
- Major onshore transmission overloads

Phase 2, Planned Approach (add 8,600 MW)

- 3 x multiterminal HVDC projects
  - 2,000 MW to Waterford (1200 MW) & East Devon (800 MW)*
  - 1,600 MW to K St. (800 MW) & Woburn (800 MW)*
  - 1,000 MW to Bridgewater
  - 400 MW HVAC project to Kent Co. RI
- 474 miles of marine cabling *(831 through Phase 2)*



*Multiterminal HVDC injecting at two locations

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Source – Brattle Group

STATCOMs

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Solutions – SVCs and STATCOMs

- Flexible AC Transmission Systems (FACTS) that provide dynamic, controllable reactive power.
- They control reactive power injection or absorption to provide dynamic voltage control, increase voltage stability, secure and enhance power supply, and increase transmission capacity.
- SVCs and STATCOMs are both doing a similar job. SVC is based on thyristor technology and STATCOMs are based on transistor (IGCT/IGBT) technology.

UK – the need to address changing power flows

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Currently Operating Coal (red) & Nuclear (yellow) Generation vs. 2025 Scenario in the UK

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Phoenix - Hybrid STATCOM - Synchronous Condenser

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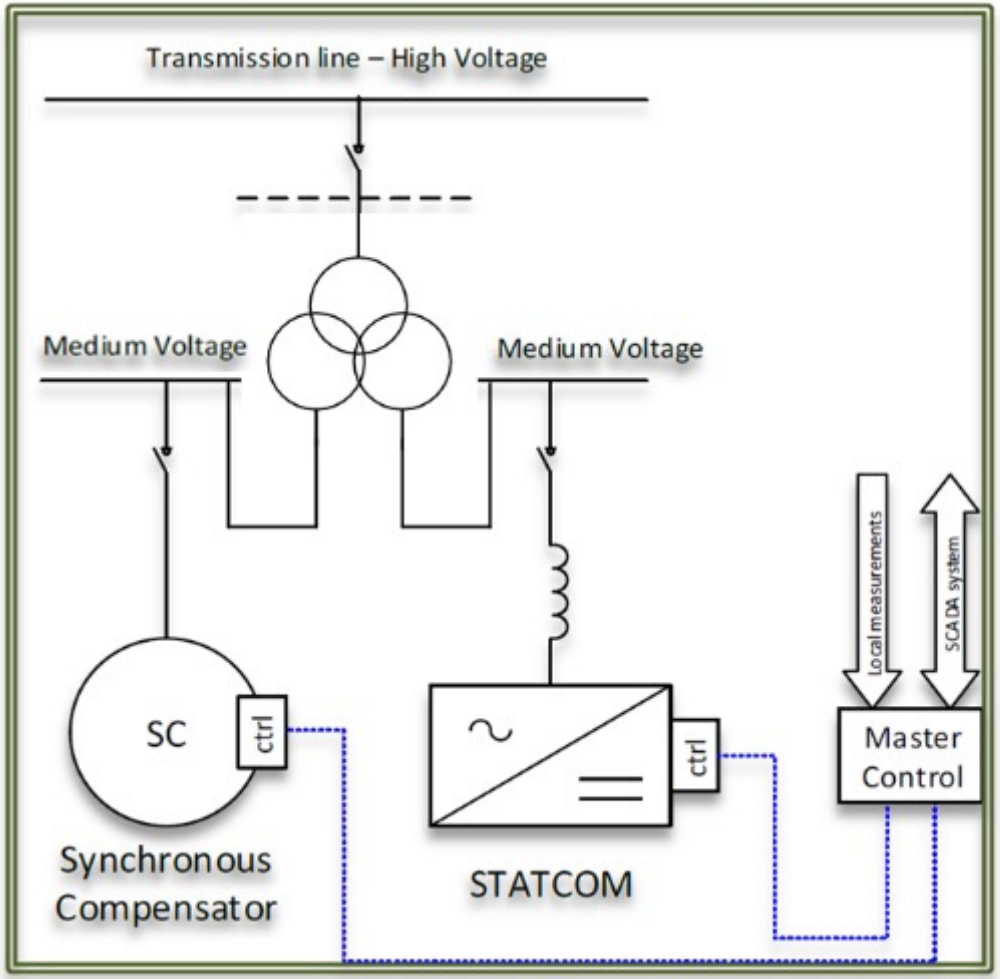
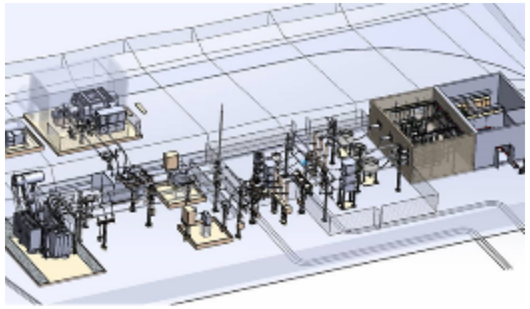


Hybrid Synchronous Condenser – Project Data

Project Purpose & Scope



Main Drivers

- Reduced System Inertia
- Reduced System Fault Level
- Limitations in Voltage Control
- Provide alternative to converting retired thermal units

Scope

- SVC Light HP STATCOM: ±70 Mvar
- Synchronous Condenser, Rated -35/+70 Mvar
- MACH® Platform Control & Protection
- Software Models and System Studies
- Civil Works, Installation, Testing and Commissioning

HITACHI ABB POWER GRIDS

Battery storage for offshore wind

- **Renewable shifting**
  Store excess renewable production to be used during peak demand hours.

- **Frequency and voltage support**
  Proprietary Virtual Generator Mode algorithms manage frequency and voltage excursions.

- **Renewable smoothing**
  Smooth out the rapid fluctuations in power output from renewable generators and dynamic loads.

- **Microgrid/islanding**
  Grid-forming, seamless transition and black start capabilities to provide power in the event of utility disruption.

- **Cybersecurity**
  Ensures high level of cybersecurity according NERC-CIP and IEEE 1686.

Steps of integration and possible issues

Integration level		Issues
	Local connection to the grid	– Reactive power and voltage control in distribution and transmission grid – Power quality – Power flow and overload control – System protection – Grid code compliance
	System wide integration	– Generation adequacy – Network enforcement and extension – Balance of load and generation, load-frequency-control – Renewable curtailments and demand response
	Market integration	– Area balancing – Price volatility – Generation forecasting – Regulation and financing schemes

Agenda

1. US Market for Offshore Wind & Grids Evolution – Fabio Fracaroli
2. Offshore Generation Technologies – Brandon Fitchett
3. Offshore Grid Technologies – Jonathan Ruddy
4. Grid Integration – Gary Rackliffe
5. **Conclusions and takeaways**

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Conclusions and Takeaways

Technology

- Connections
  - AC and DC nuances
    - Grid-Forming
  - Multiple POIs
- Digital integration
  - Generation, transmission & distribution, Substations

Planning

- Power Studies
  - POIs, Grid connection
  - Meshed Grids or Single Lines?
  - Long-term planning can allow study of multiple options
- System Goals?
  - Minimize congestion
  - Maximize Reliability
  - Inertia, Short circuit levels
- Environment and Public

Coordination

- Collaborative R&D and Design
  - Systems vs. components
  - Power system goals vs. site incentives/contracts
- Stakeholders
  - Multi-organizational – Site, Power System, Utilities, Investors, Public
  - Multi-state, Multi-National (Learn from Europe)

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NOWRDC Webinar -

Opportunities in Offshore Wind Grid Integration

March 19, 2021

Questions?

Any additional follow-up may be directed to juergen@nationaloffshorewind.org

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