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NRG Park

OTC-26922-MS

Smart Novel Semi-Active Tuned Mass Damper for Fixed-Bottom and Floating Offshore Wind

A. Rodriguez Tsouroukdissian,
GE Renewable Energy

What’s our playground?

The GE-Haliade* 150-6 MW

A unique wind turbine to serve our customers' needs

High aerodynamic efficiency
Convert wind into energy

Direct Drive, permanent magnets generator
No gearbox, no risk of failure, no oil

Tuned Mass Damper
Reduces foundation cost and allows Monopiles where jackets could be required

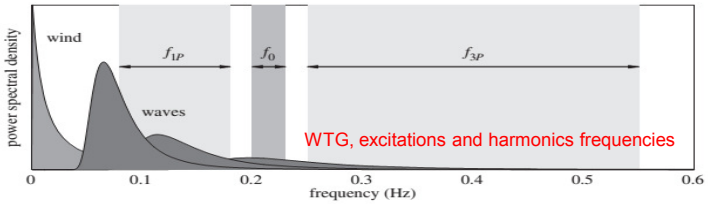
Individual electrical Pitch
Minimize loads, increase components lifetime at reduced cost

Pure Torque®
ensures reliability and efficiency of the generator

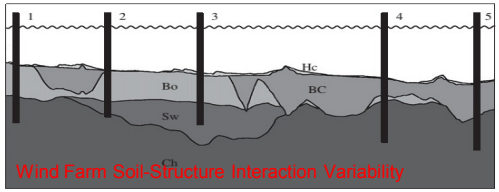
Redundant sub-systems
ensures energy production

A bankable wind turbine constantly ensuring generation of electricity at any time, at the lowest cost…

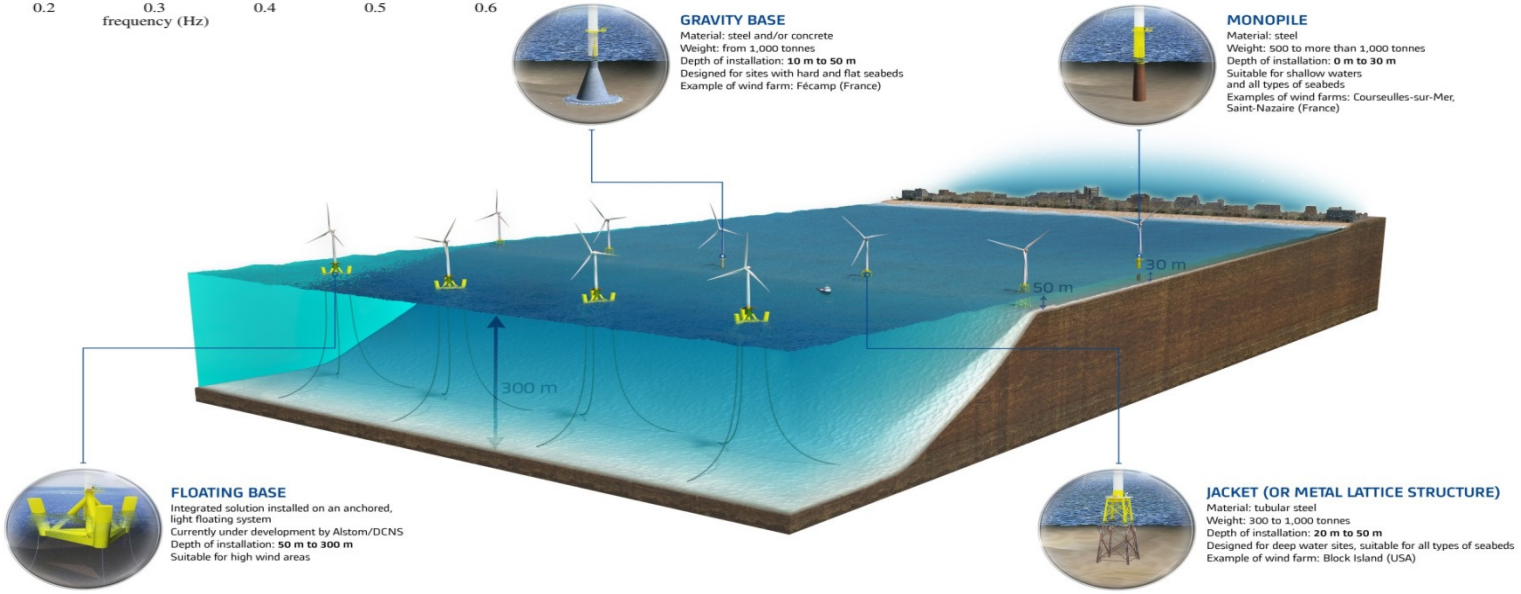
Where will we install our WTG?



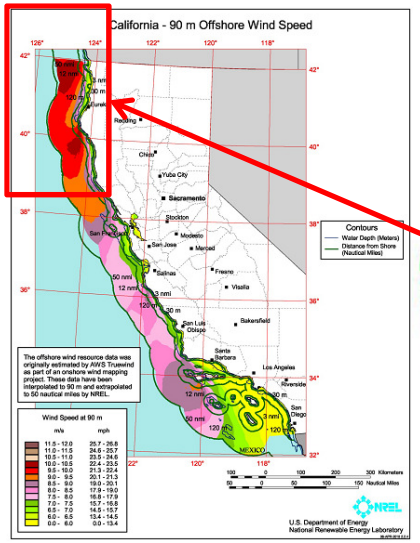
WTG, excitations and harmonics frequencies

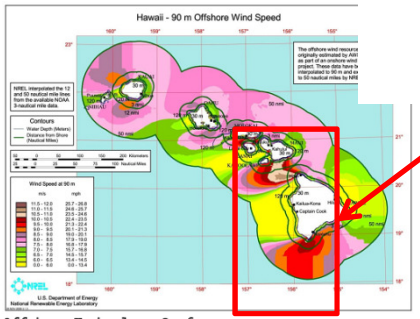


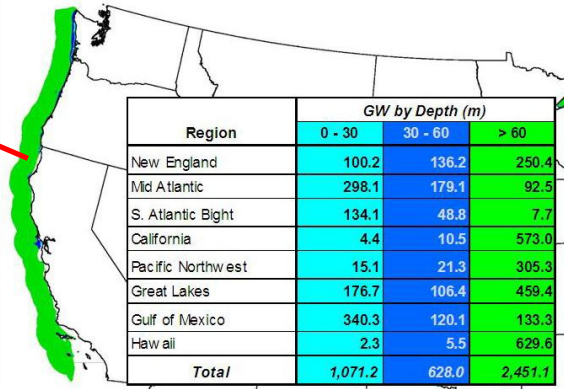
Wind Farm Soil-Structure Interaction Variability



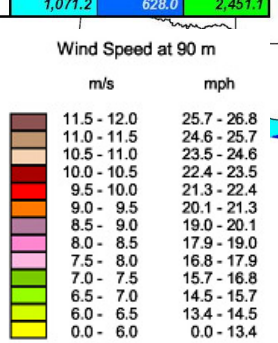
US Offshore Wind Resources

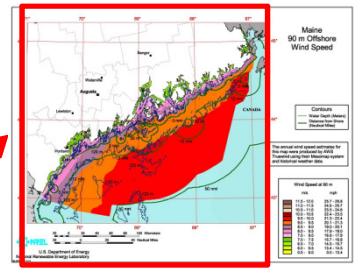


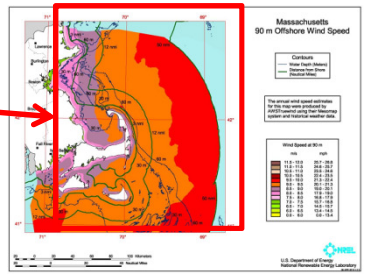


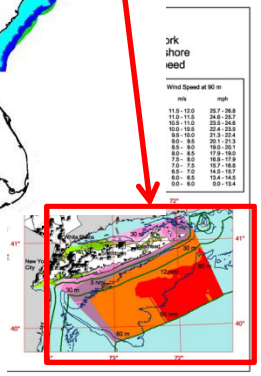


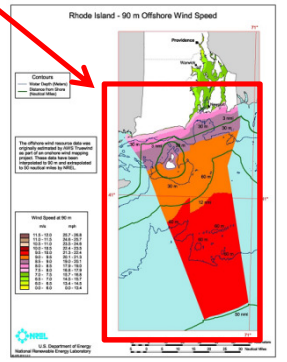
Region	GW by Depth (m)		
	0 - 30	30 - 60	> 60
New England	100.2	136.2	250.4
Mid Atlantic	298.1	179.1	92.5
S. Atlantic Bight	134.1	48.8	7.7
California	4.4	10.5	573.0
Pacific Northwest	15.1	21.3	305.3
Great Lakes	176.7	106.4	459.4
Gulf of Mexico	340.3	120.1	133.3
Hawaii	2.3	5.5	629.6
Total	*1,071.2*	*628.0*	*2,451.1*





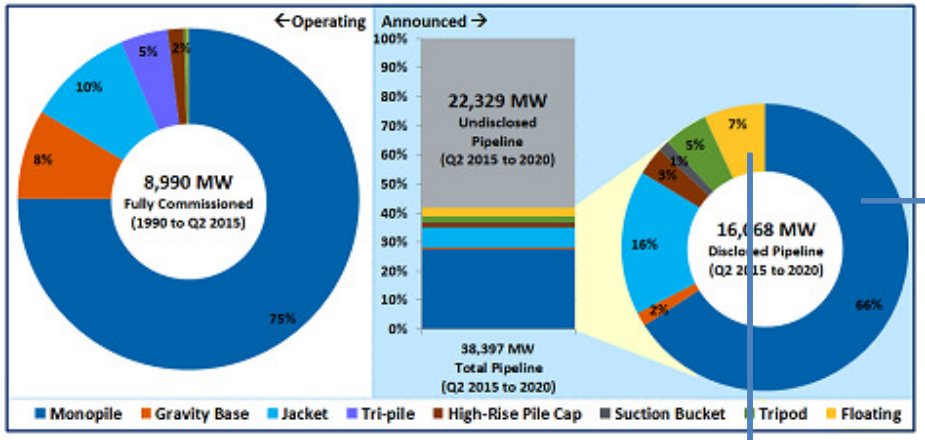




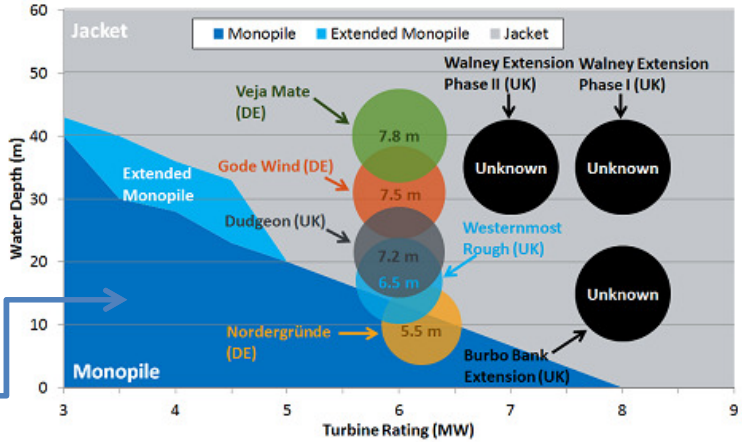


Source: NREL

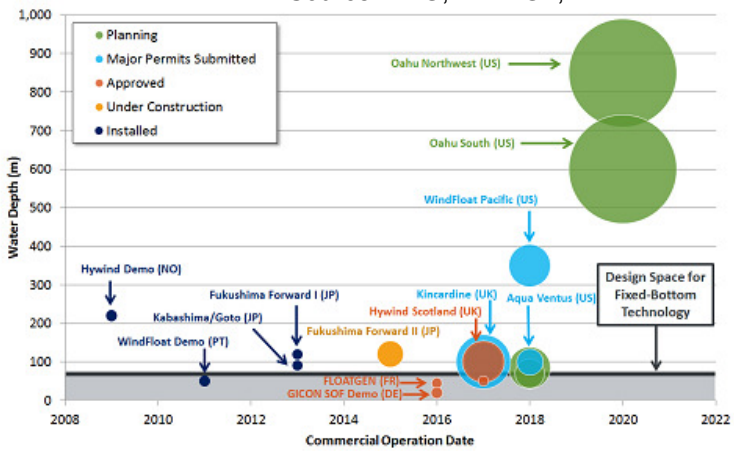
Fixed-Bottom & Floating Substructures Trends



Source: BVG, DNV-GL, NREL



Source: BVG, DNV-GL, NREL

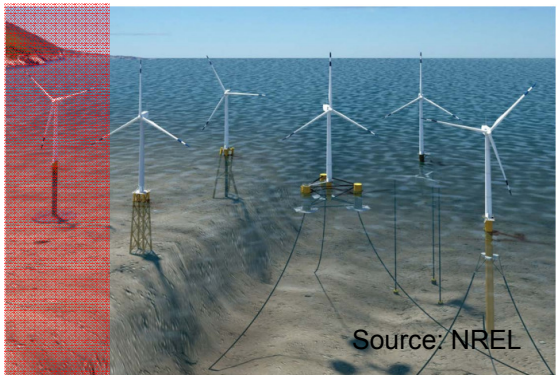


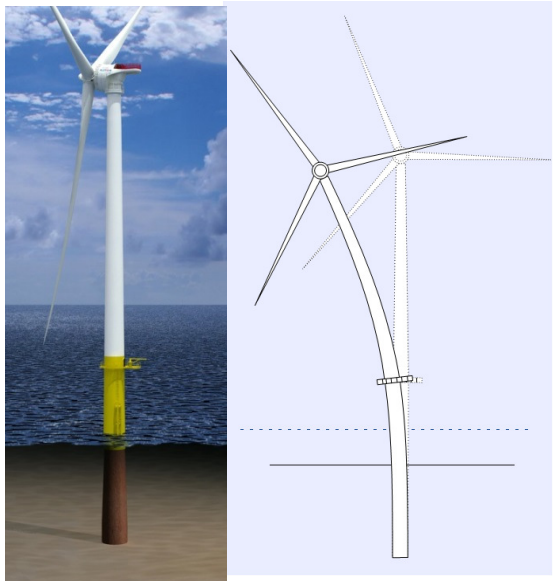
Monopile Challenges

- Vary diameter to meet frequency requirements
- Diameter at mudline governed by FLS
- Increase penetration to bear ULS loads
- Increase wall thicknesses to ensure adequate fatigue lives

- <u>5 to 25m water depth:</u>
  1. Design is dominated by wind loads,
  2. Dynamic effects of wave loads have some importance,
  3. Eigen frequency still is the most relevant parameter for load level.

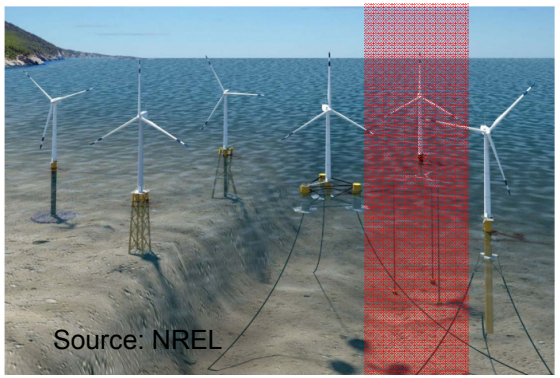
- <u>25 to 35m water depth:</u>
  1. Design driven by wave loads,
  2. Dynamic effect of wave loads is of primary importance,
  3. Sensitivity to soil-stiffness and damping has increased.





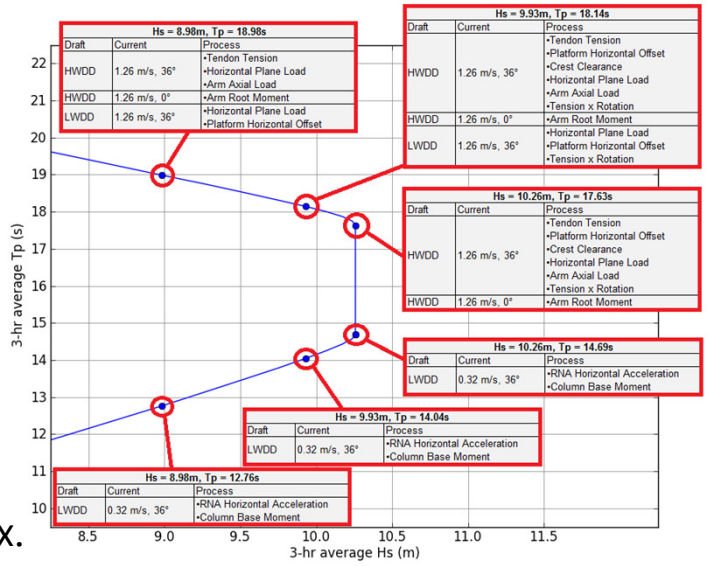
TLP Challenges

- Vary diameter to meet frequency requirements
- Diameter of tower is governed by FLS fore-aft and side-to-side
- High surge accelerations are of relevance for non-structural components



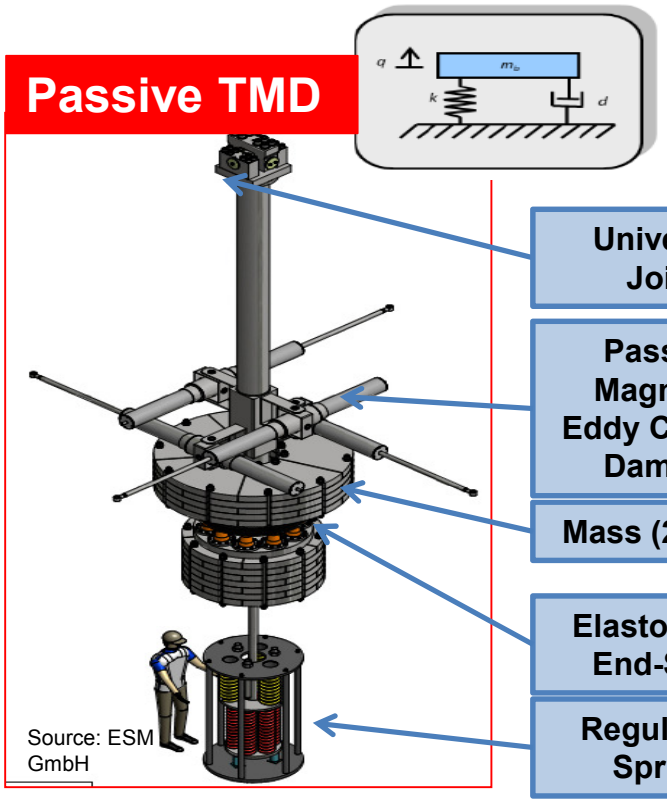
- <u>50 to 75m water depth:</u>
  1. Design driven by extreme wind & wave loads,
  2. System frequencies on top of wave spectrum,
  3. Slack line event is a design driver for tower and substructure system.

- <u>75m to 350m on water depth:</u>
  1. Design is dominated by wind loads,
  2. Dynamic effects of wave loads have some importance,
  3. Mooring systems are sensible to current induced vortex.



Can we mitigate these challenges?

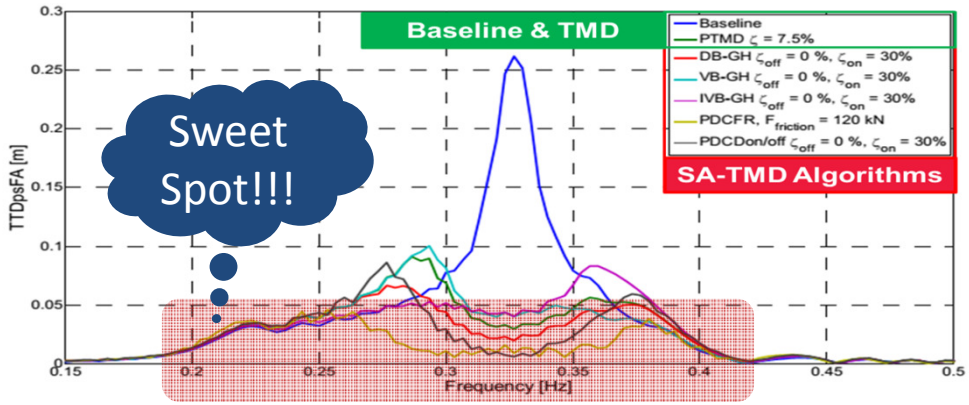
Passive Dampers Pros & Cons



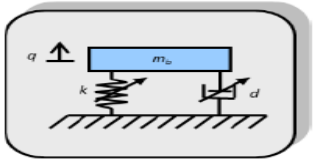
- Universal Joint
- Passive Magnetic Eddy Current Damper
- Mass (20Ton)
- Elastomeric End-Stop
- Regulation Spring

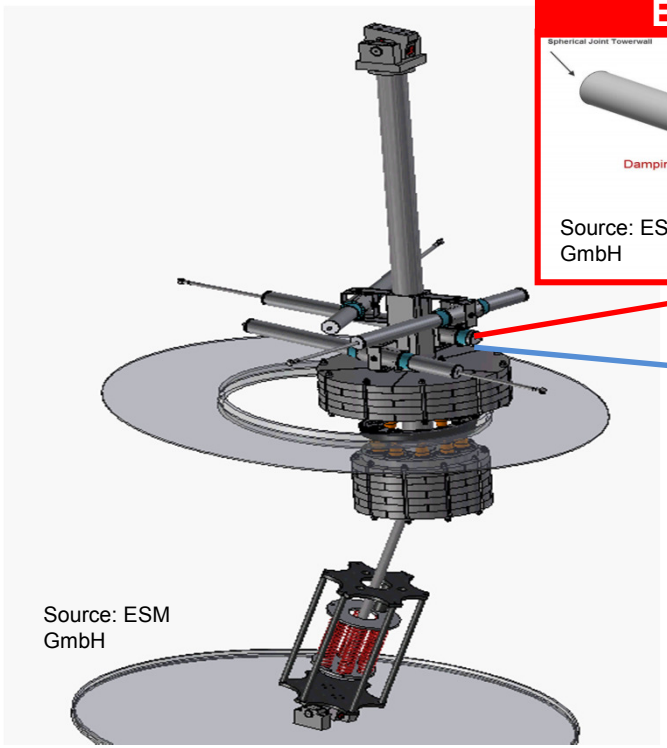
What can we improve?

1. Add more damping (+30%)
2. Reduce TMD excursions (0.7m)
3. Lower resonant amplitude at wider frequency band (+/-10%)



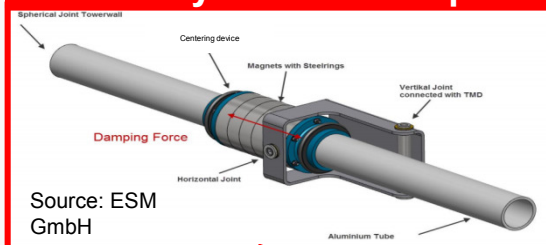
What's a semi-active system?





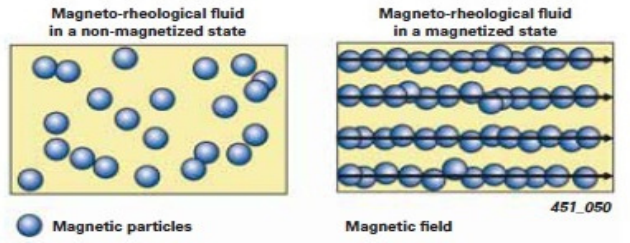
Source: ESM GmbH

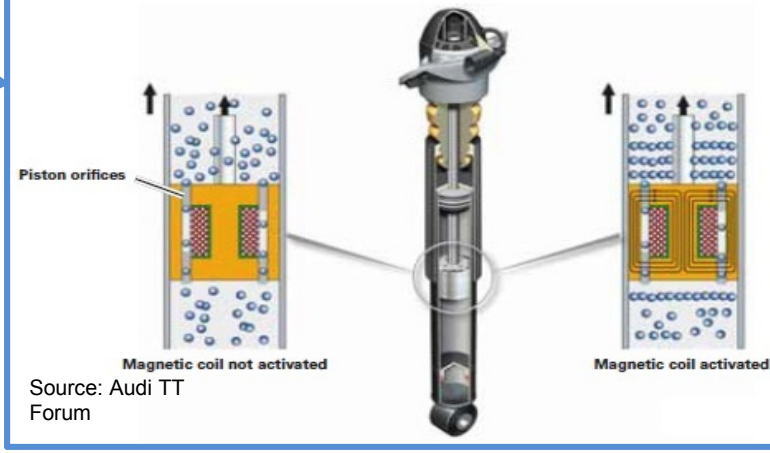
Eddy Current Damper or



Source: ESM GmbH

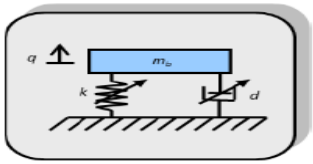
Magnetorheological (MR)Damper

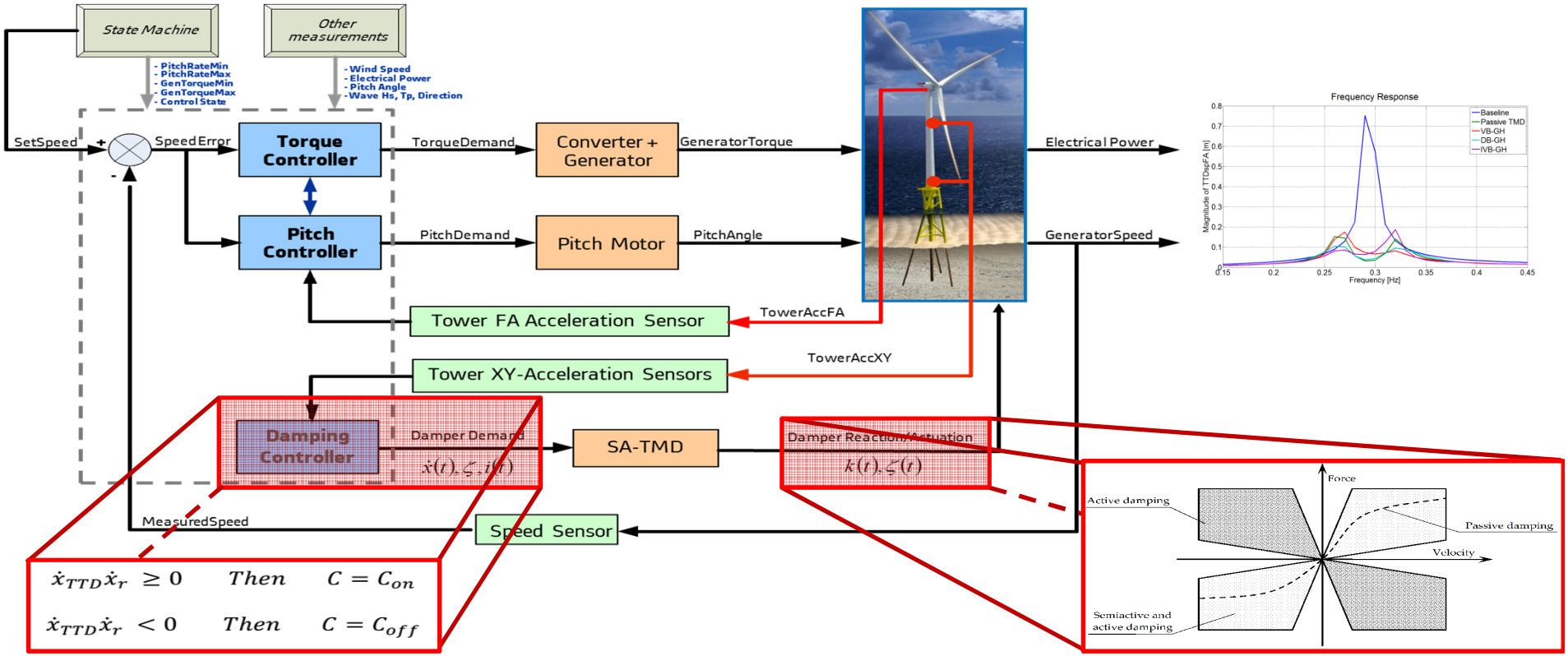




Source: Audi TT Forum

SA-TMD Solution Integration

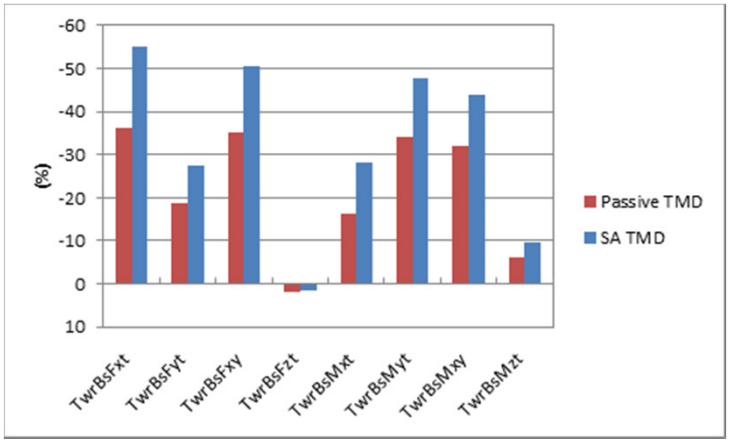


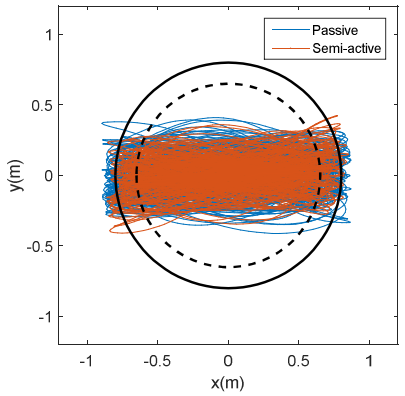


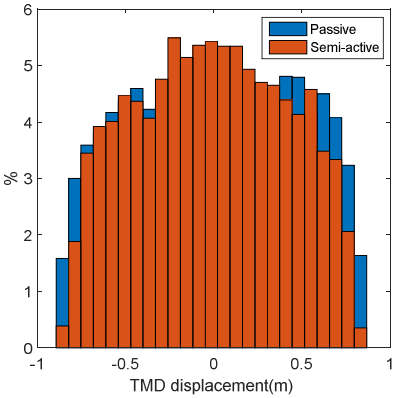
How’s the Monopile system response?

Extreme DLC Load Reduction

- Tower Base Loads are reduced by 33% with a Passive-TMD & 44% with a SA-TMD.
- SA-TMD reduces the excursions of the TMD even in the non-linear regime.



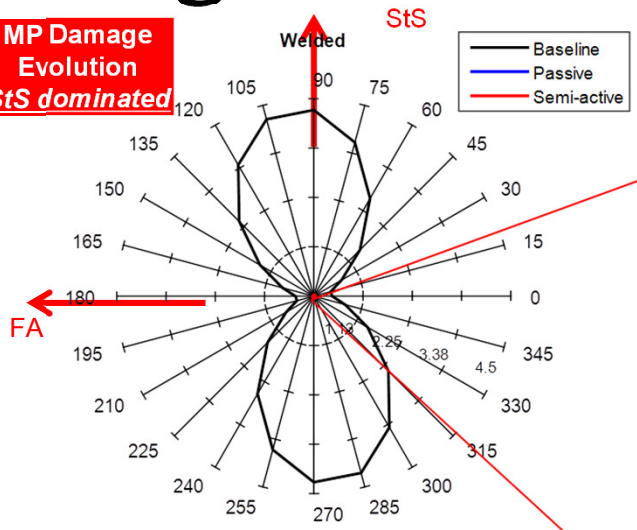


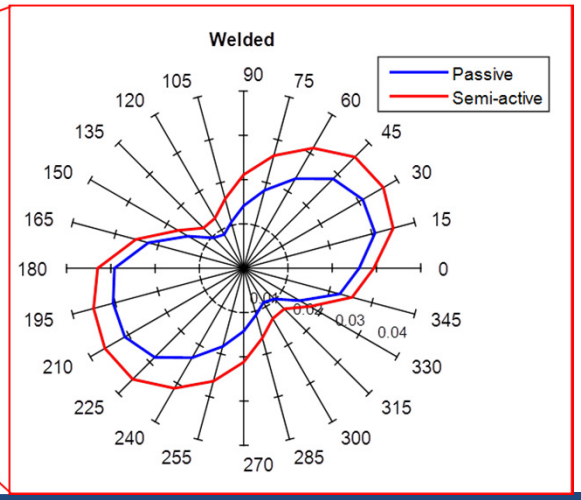


TMD effectiveness increases for SA-TMD case vs Passive-TMD under extreme events

Fatigue DLC Load Reduction

MP Damage Evolution
StS dominated



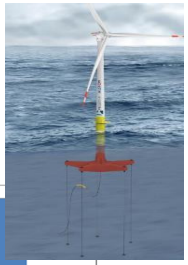


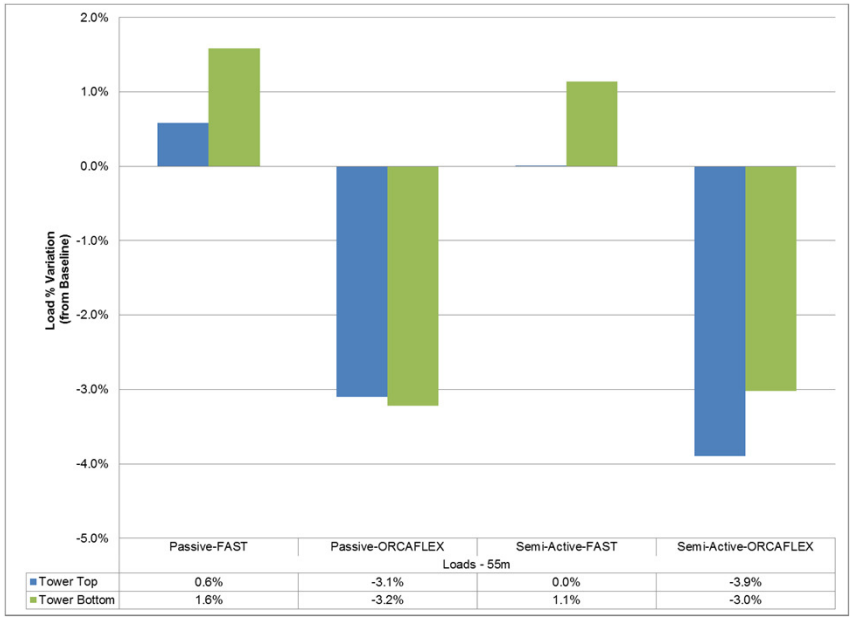
Tower Base m=3 DEL's
Passive-TMD reduces Mx 69% & SA-TMD reduces 66% from Baseline

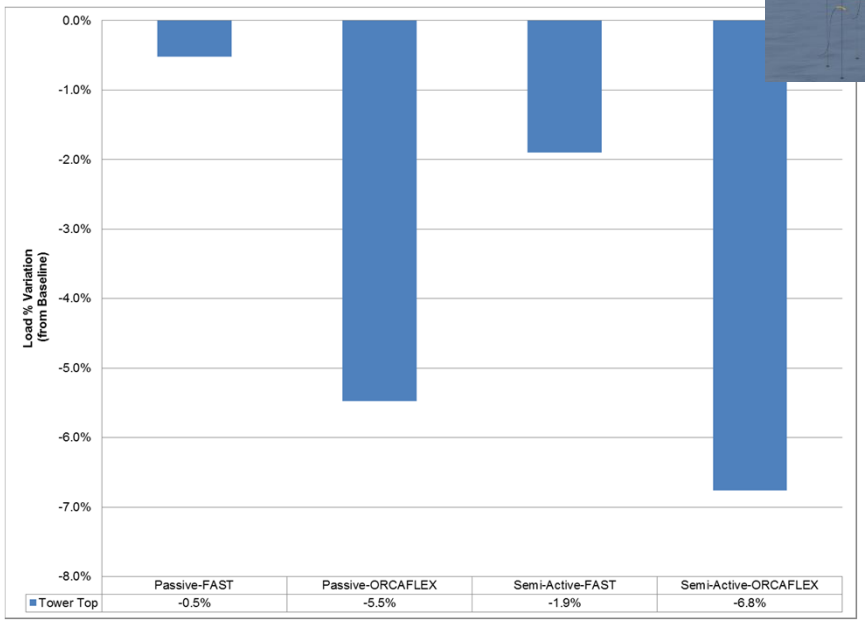
TMD reduces both Passive-TMD and SA-TMD FLS loads in StS

How’s the TLP system response?

Extreme DLC Load Reduction

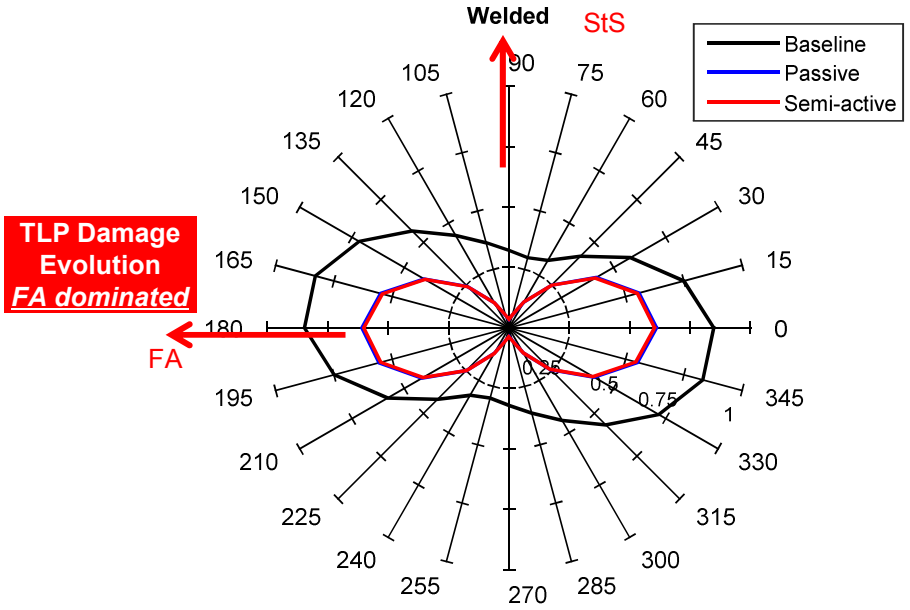






TMD effectiveness for both Passive-TMD and SA-TMD is perceived more pronounced using Orcaflex non-linear code rather than FAST linear code

Fatigue DLC Load Reduction



Tower Base m=3 DEL's for Passive-TMD reduces My 10% & SA-TMD reduces 11% from Baseline

TMD reduces both Passive-TMD and SA-TMD FLS loads in FA

Summary & Next Steps

Summary & Next Steps

- **Offshore wind farms present several challenges in system response.**

- **Structural damping control devices mitigate unwanted loads that drive the system and LCOE.**

- **Semi-active dampers are a promising technology that are able to suppress a broad band of frequencies.**

Acknowledgements / Thank You / Questions

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POWER	ENERGY MANAGEMENT	RENEWABLE ENERGY	OIL & GAS	AVIATION	TRANSPORTATION	HEALTHCARE	APPLIANCES & LIGHTING
~$30B	~$11B	~$9B	$18.7B	$24B	$5.7B	$18.3B	$8.4B
66K EMPLOYEES	47K EMPLOYEES	13K EMPLOYEES	46K EMPLOYEES	45K EMPLOYEES	13K EMPLOYEES	55K EMPLOYEES	25K EMPLOYEES

2014 REVENUES

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Integrated Solutions
For Offshore Wind Farms
Onshore DC/AC Converter Station & AC Substation
For far offshore wind farms DC often provides the best techno-economic solution for transmission to the shore. Leader in HVDC with over 30,000 MW of installed capacity worldwide, GE has developed efficient grid connections.
Offshore AC Substation
To connect the offshore wind farm to the onshore electricity network or to an AC/DC converter station, GE supplies several types of offshore wind substations, such as selffloating and self installing solutions.
Offshore AC/DC Converter Station
To convert the power generated by the wind turbines in alternating current (AC) to direct current (DC) for transmission to shore, GE offers the HVDC MaxSine* VSC technology for sustainable grid connections.
Haliade* 150-6MW
Built upon GE's Pure Torque* technology for reliability, the turbine features a 6 MW direct-drive permanent magnet generator and is suitable for all offshore conditions.
From Wind Turbine Installation to Grid Connection
- A reliable, efficient and high yield offshore wind turbine
- An innovative AC platform and efficient transmission over long distances with HVDC technology
Non proportional scale image. *Trademark of General Electric Company