OFFSHORE WIND ENERGY DEVELOPMENT
IN THE ADRIATIC SEA:
THE P.O.W.E.R.E.D. PROJECT AS PLANNING POLICY

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A new generation of wind turbines to bring down the cost of offshore wind power

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THE OFFSHORE WIND POWER BETWEEN POTENTIALITY AND REALITY

- There is a great demand of energy in the world
- There is a huge potentiality of offshore wind power in deep waters
- The forecast demand is more than 20 000 MW by 2020
- However the extraction cost is the watershed between potentiality and reality
- Condor Wind Energy owns a technology able to extract energy from offshore deepwater sites at costs which are competitive with those of other sources of energy:

Site mean wind	**7 m/s**	**8 m/s**	**9 m/s**
€/MWh	92	72	60
Cost based on a 400 MW wind farm			

CONDOR TECHNOLOGY

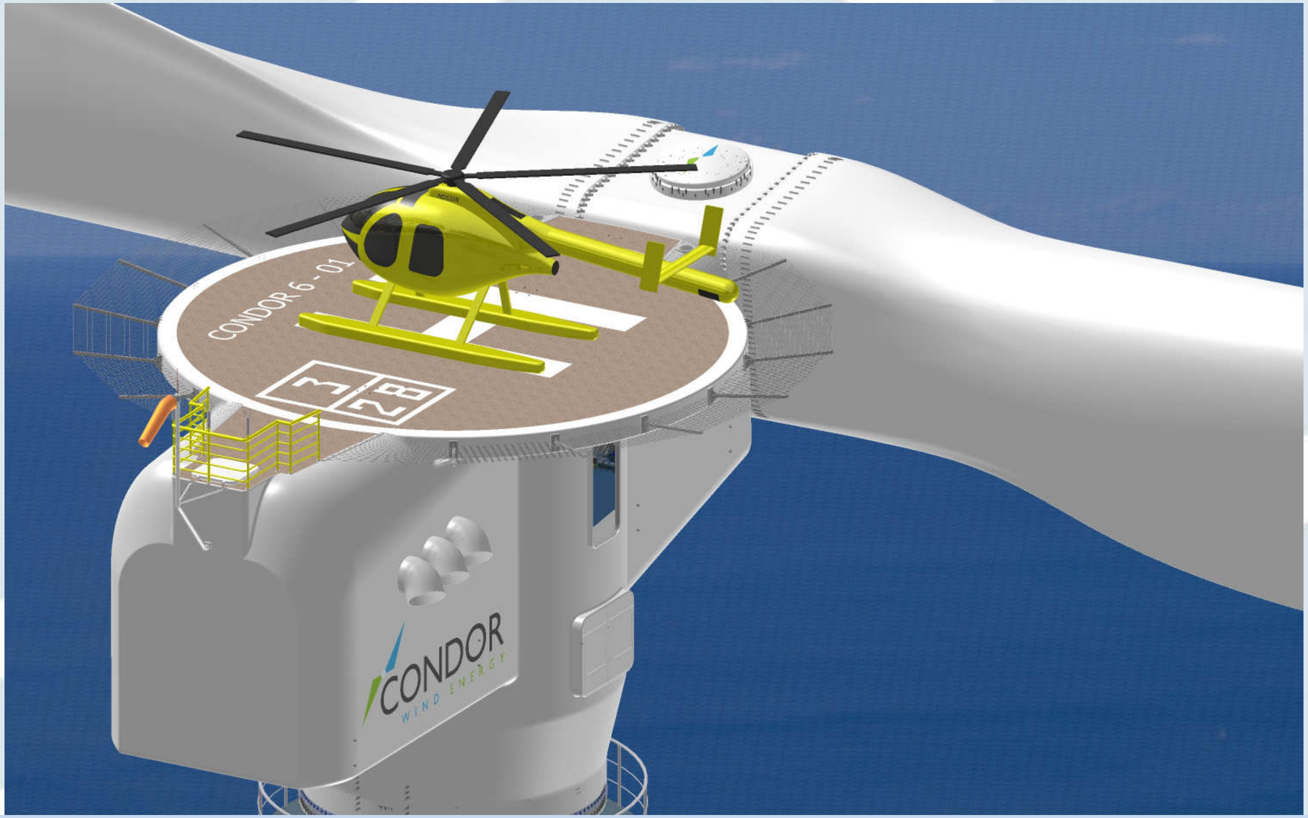
DESIGNED TO LOWER ANY COMPONENT OF COST

- Turbine fabrication
- Support structure fabrication
- Assembly at shipyard and launch
- Transport from shipyard to the site and installation
- Operation and maintenance

THE COST SHARE OF A 400 MW DEEP WATER WIND FARM BY CONDOR TECHNOLOGY

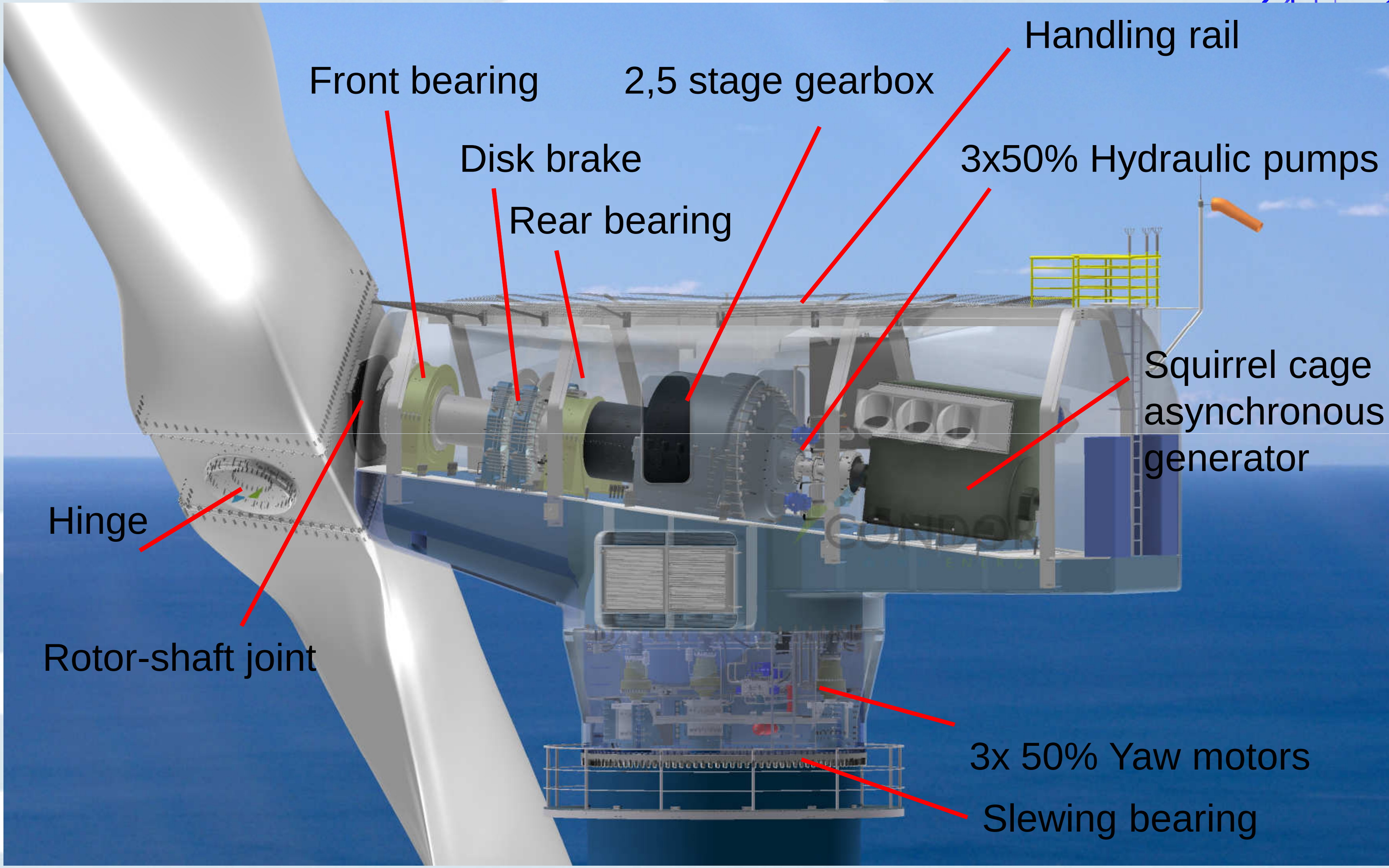
	%
Turbines	37.5
Support structures	29.6
Assembly at shipyard and launch	5.2
Transport from shipyard to the site and installation	11.9
Wind farm electrical system	12.8
Wind farm development	3.0

THE CONDOR TURBINE TECHNOLOGY , SPECIFICALLY DESIGNED FOR OFFSHORE DEPLOYMENT



- Condor 6 (6.1 - 6.4 MW)
- Two-bladed, teetering hinge, yaw control, variable speed
- No pitch, no stall

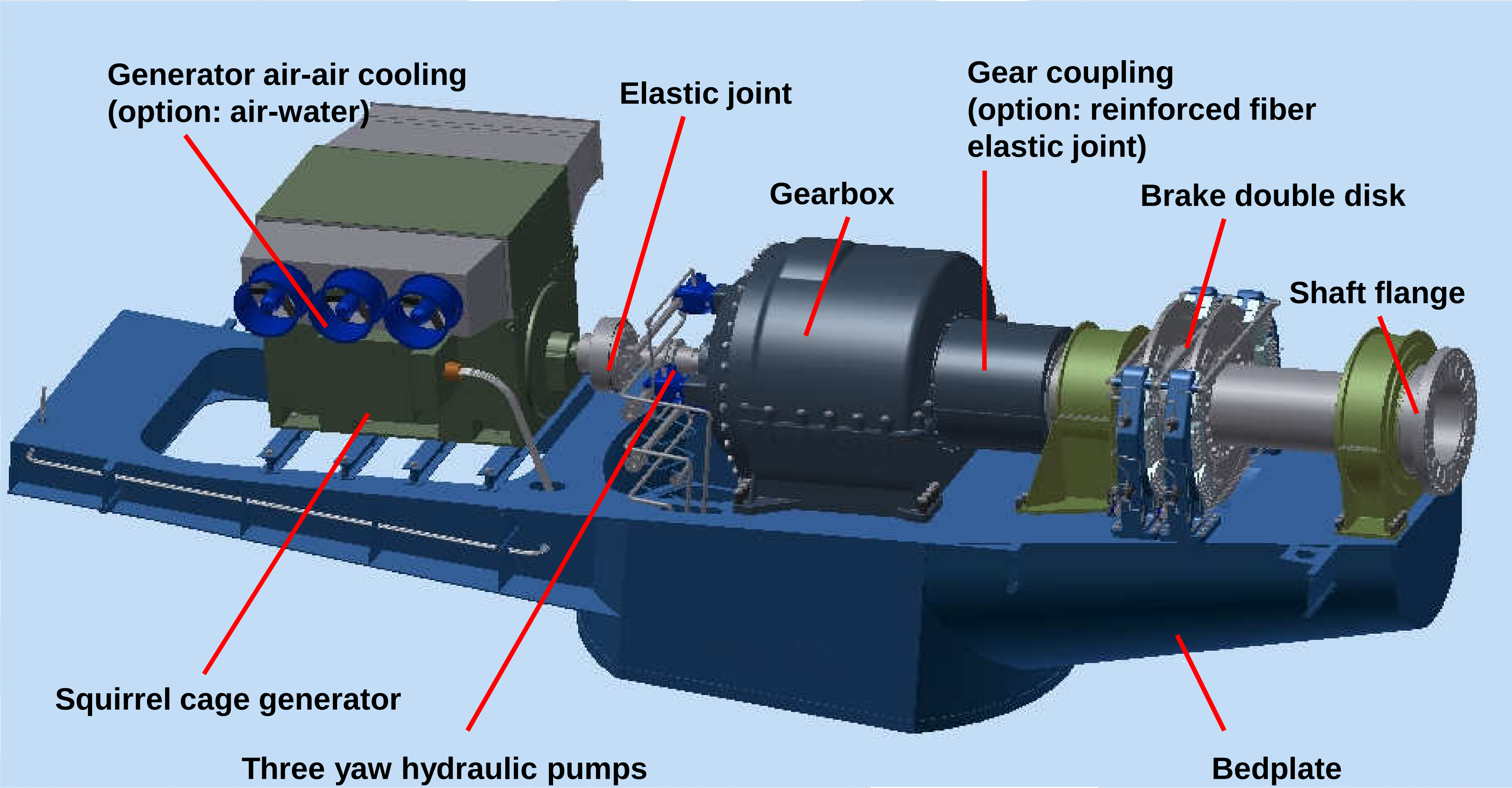
THE CONDOR TURBINE TECHNOLOGY



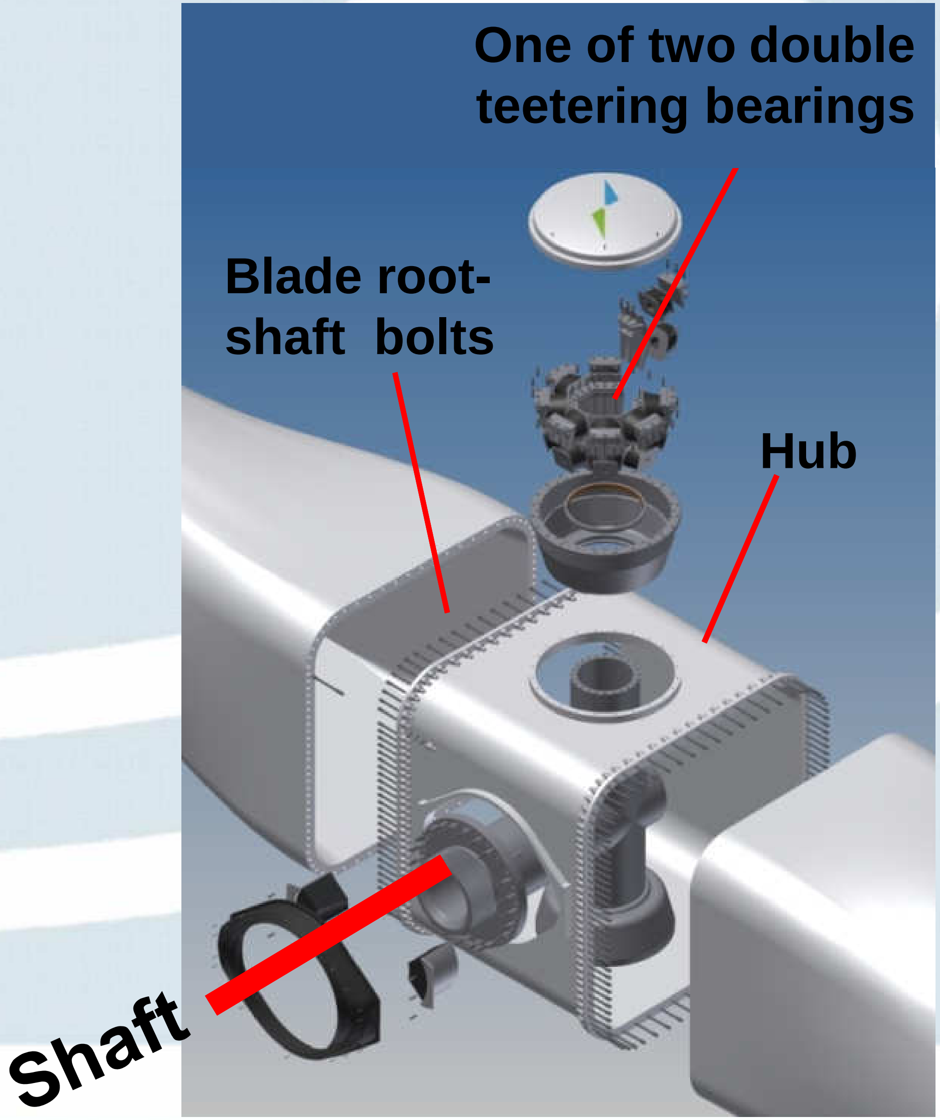
CONDOR 6 DESIGN DATA

Parameter	Condor 6
Rated power	6.1
Max power	6.4 MW
Rotor diameter	125m
Rated running speed	19.4 - 20.4 rpm
Wind speed at rated power	12.4 m/s
Wind speed at rated torque	11.1 m/s
Rated rotor torque	3000 kNm on average
Rated rotor thrust	900 kN on average
Gearbox ratio	34.8 (2.5 stages)
Yaw torque capacity	3 motors of 1019 kNm each
Mech. brake capacity	13000 kNm
Blade weight	16.9 t
Weight of nacelle & rotor	250 t

CONDOR 6 DRIVETRAIN

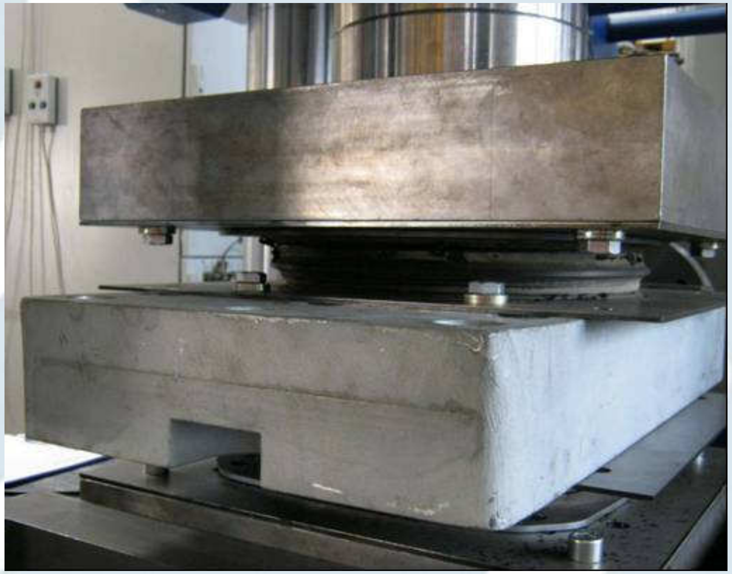


CONDOR 6 TEETERING HINGE



ACCELERATED FATIGUE TESTS AT ESM SHOP

Elementary teeter

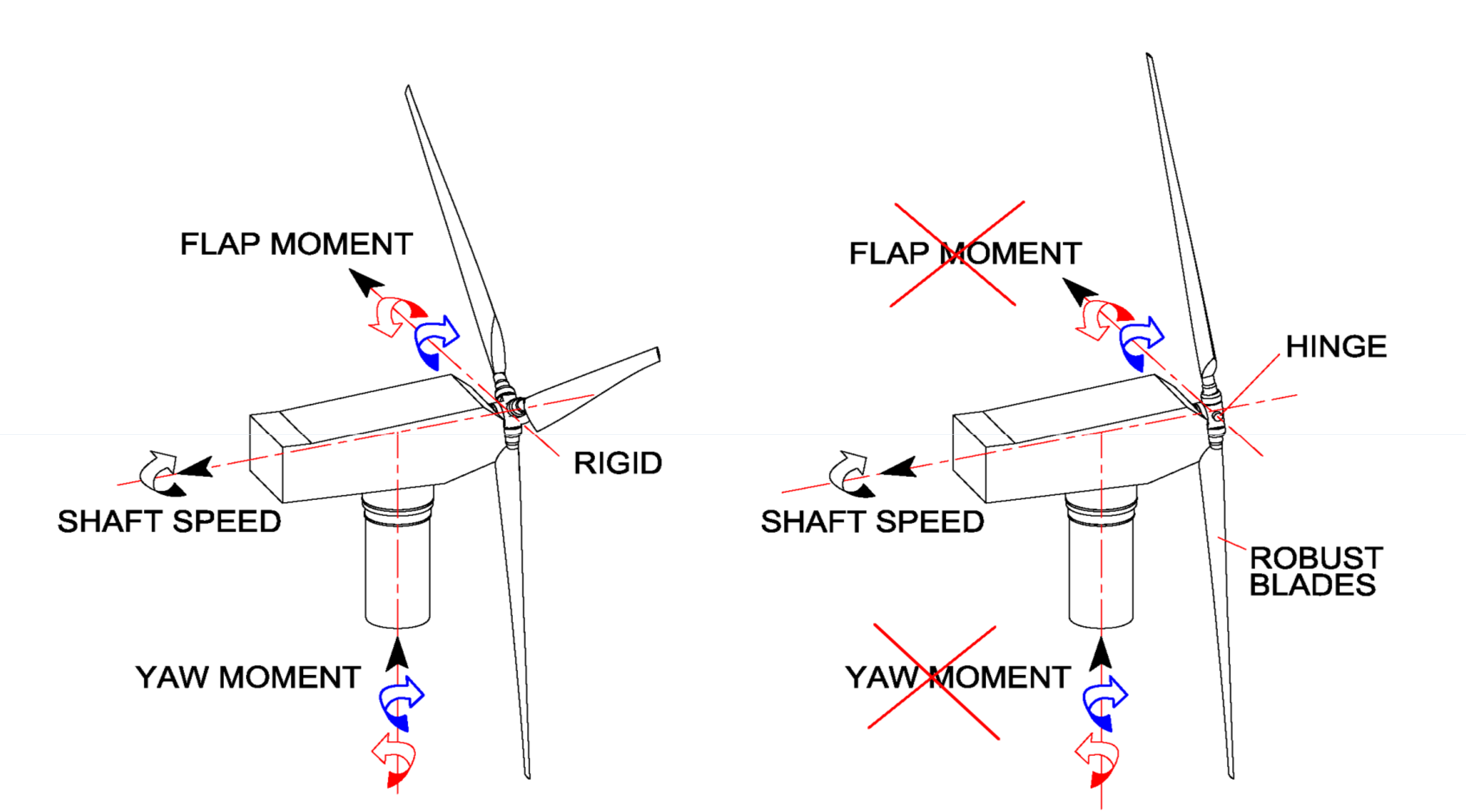


Test facility

For an equivalent shear of ±4.5° 10^7 cycles:

NO cracks in the rubber.

TWO-BLADED TEETERING VS THREE-BLADED RIGID ROTOR

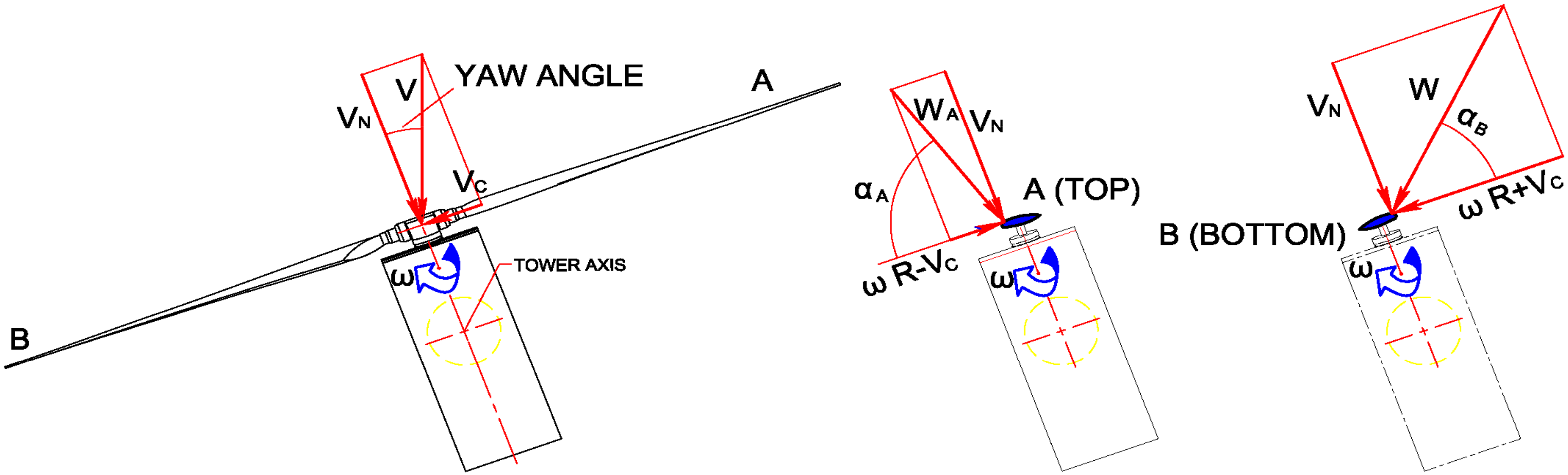


Shaft lower speed, higher torque

Shaft higher speed, lower torque

ORIGIN OF 1P TEETERING IN TWO-BLADED YAW CONTROL TURBINES

- **Origin**: different angles of attack due to combination of yaw angle and wind shear on vertical blades: the two causes however are of opposite sign
- **Amplitude**: depending on pitch error, rotor running speed, yaw acceleration, hinge torsional stiffness, rotor damping in air



NO DIFFERENT EFFECT OF CROSS FLOW V_C ON ANGLE OF ATTACK α_A, α_B IN A, B (HORIZONTAL BLADES)

DIFFERENT EFFECT OF CROSS FLOW V_C ON ANGLE OF ATTACK α_A, α_B IN A, B (VERTICAL BLADES)

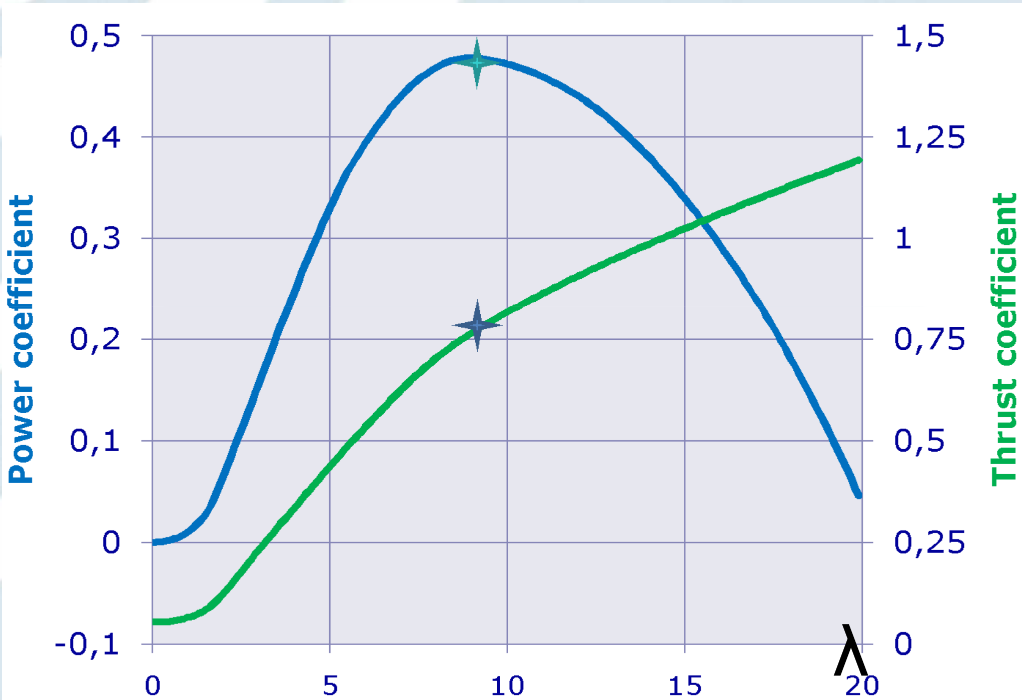
TEETERING AMPLITUDE

- The Condor 6 functional analysis was performed by the last version of GH Bladed equipped with the Condor control software.
- The teetering amplitude results similar to that experienced by the predecessor two-bladed 4 MW turbine WTS-4 and lower than the predecessor two-bladed yaw control 1.5 MW turbine Gamma 60 tested in Sardinia in late 90's.
- The max teetering magnitude at the highest wind speed and max yaw angle is $\pm 4°$.
- At shutdown in the worst condition the teetering angle can see one or half cycle at $\pm 6°$.
- It was found by analysis and by testing that the max teetering angle is reached with the blades almost in horizontal position, as result of unbalancing loads which has the max values with the blades in vertical position.

THE CONTROLLER: TWO CONTROL LOOPS

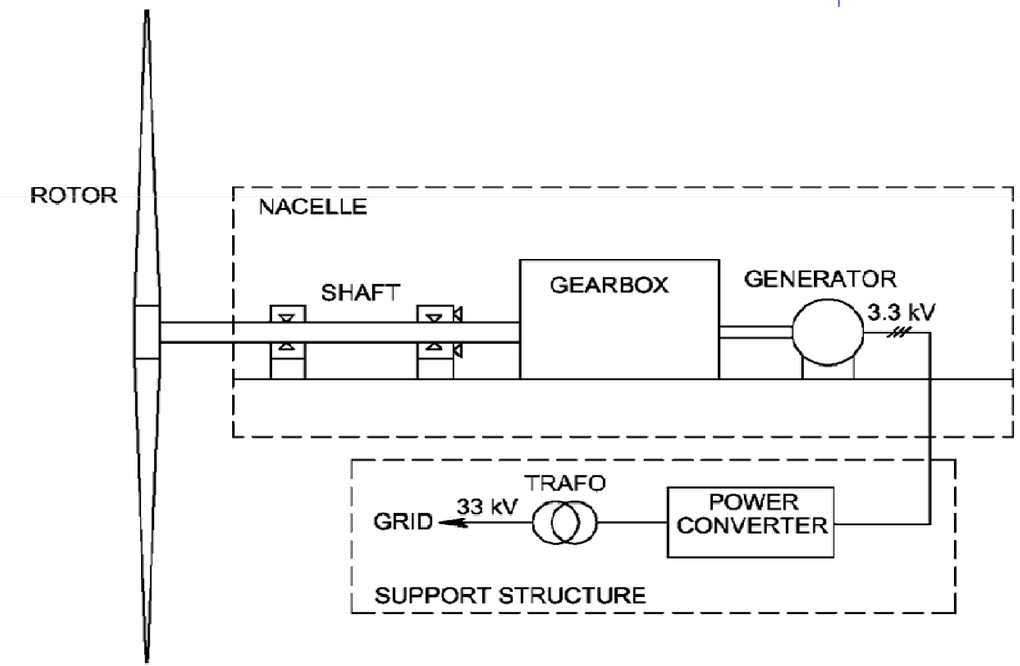
- The electrical torque control loop, to have λ = const till rated power; torque const at rated power

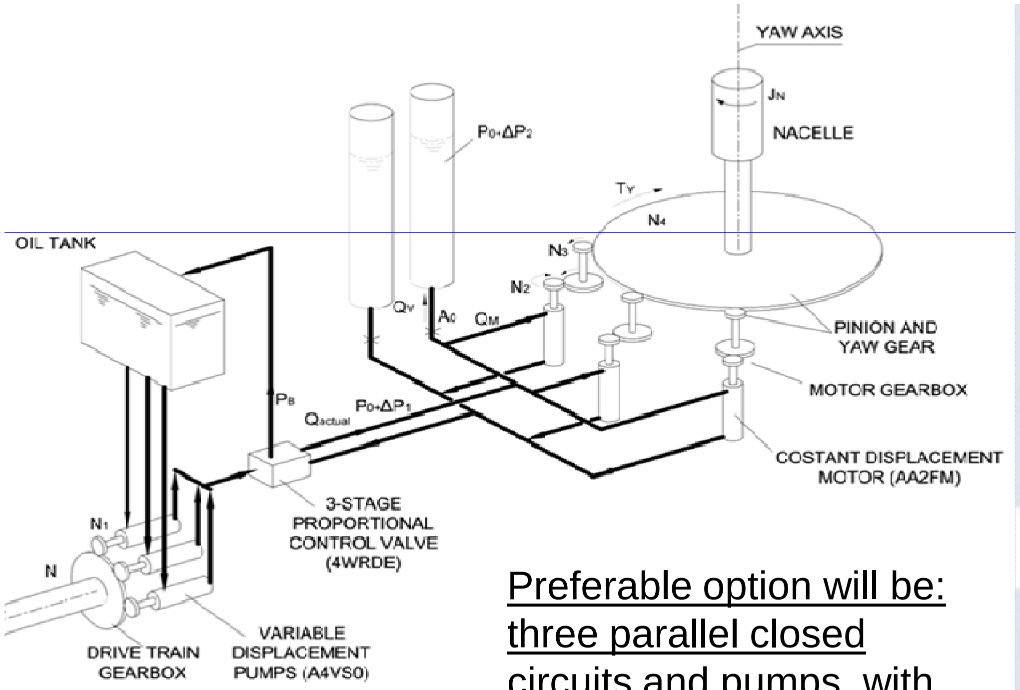
- The yaw angle control loop, to have: angle = 0 till rated power; rated rotor speed at rated power



MEANS TO MODULATE TORQUE AND YAW ANGLE

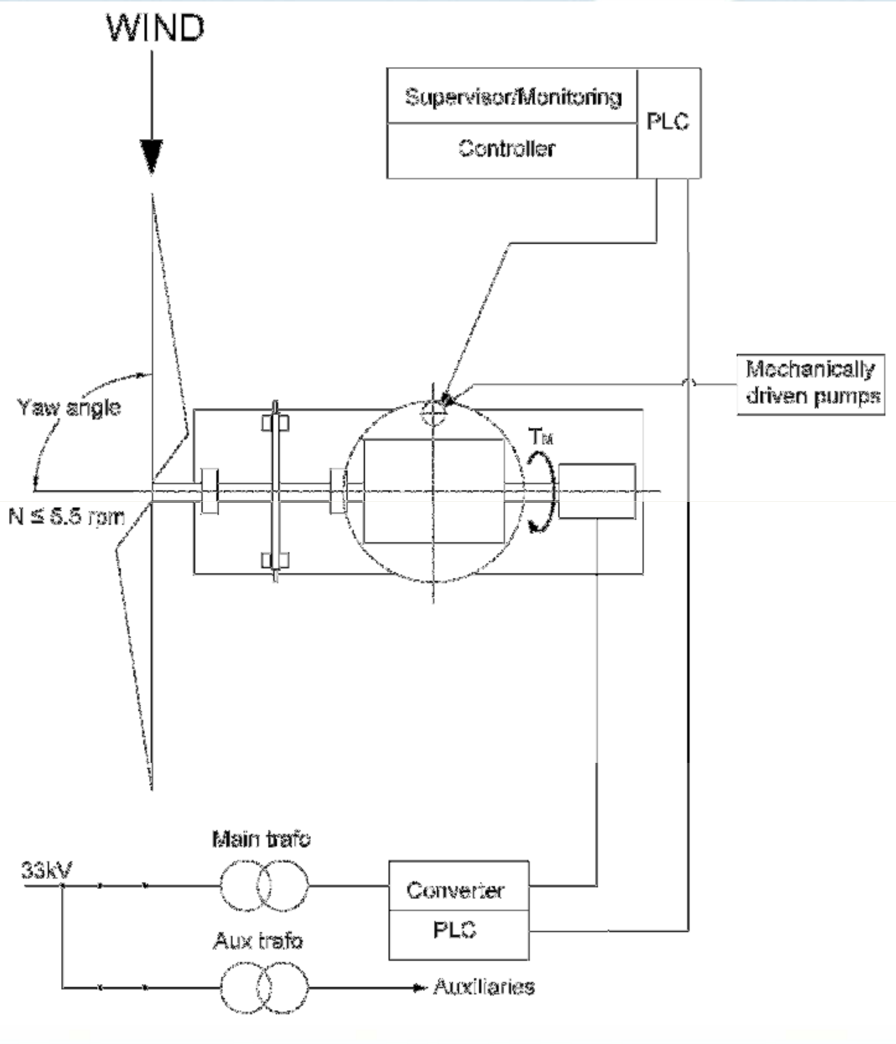
- Electrical generator/converter
- Triple yaw actuation system 3x50% (plus 2x100% electrical pumps for parking)





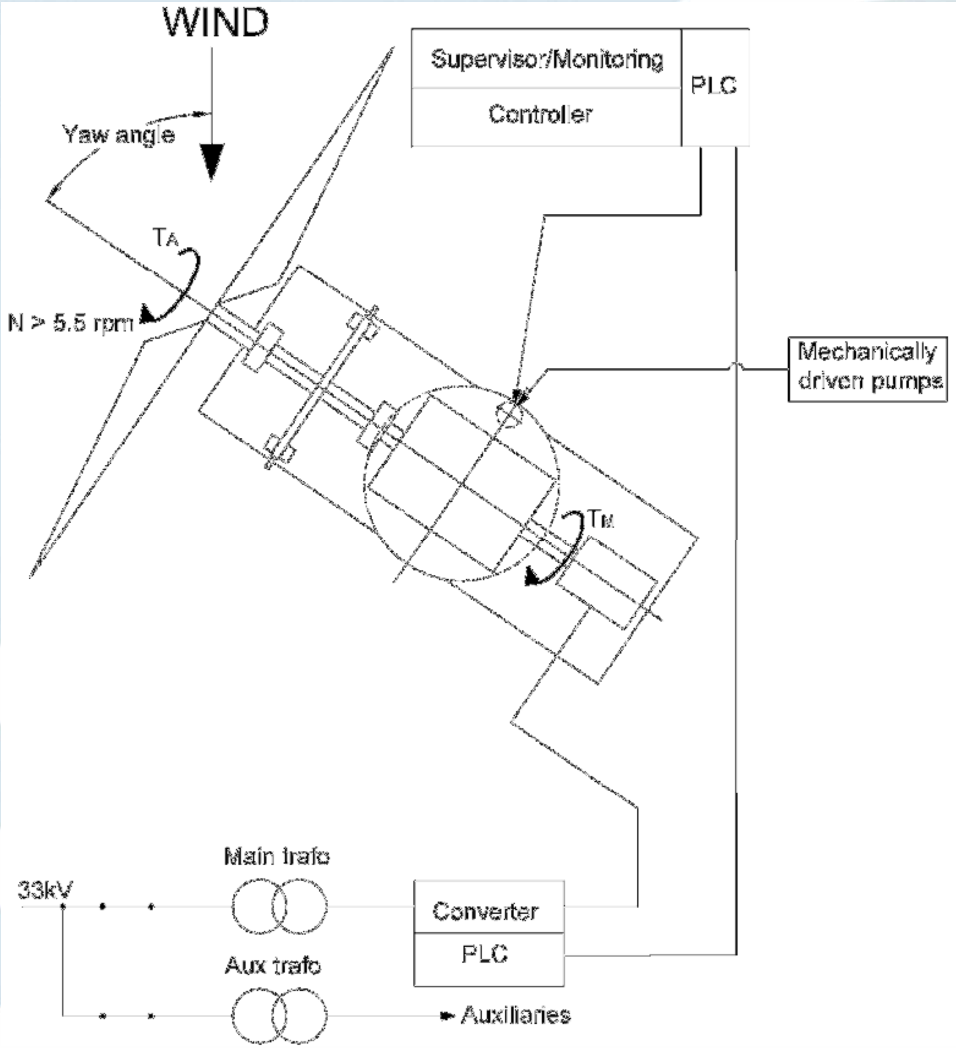
<u>Preferable option will be: three parallel closed circuits and pumps with swash plate for control</u>

OPERATION MODALITY - START-UP INITIAL STAGE



- The rotor is moved to 5.5 rpm by the generator used like a motor
- The motoring torque is set by the "torque control loop"

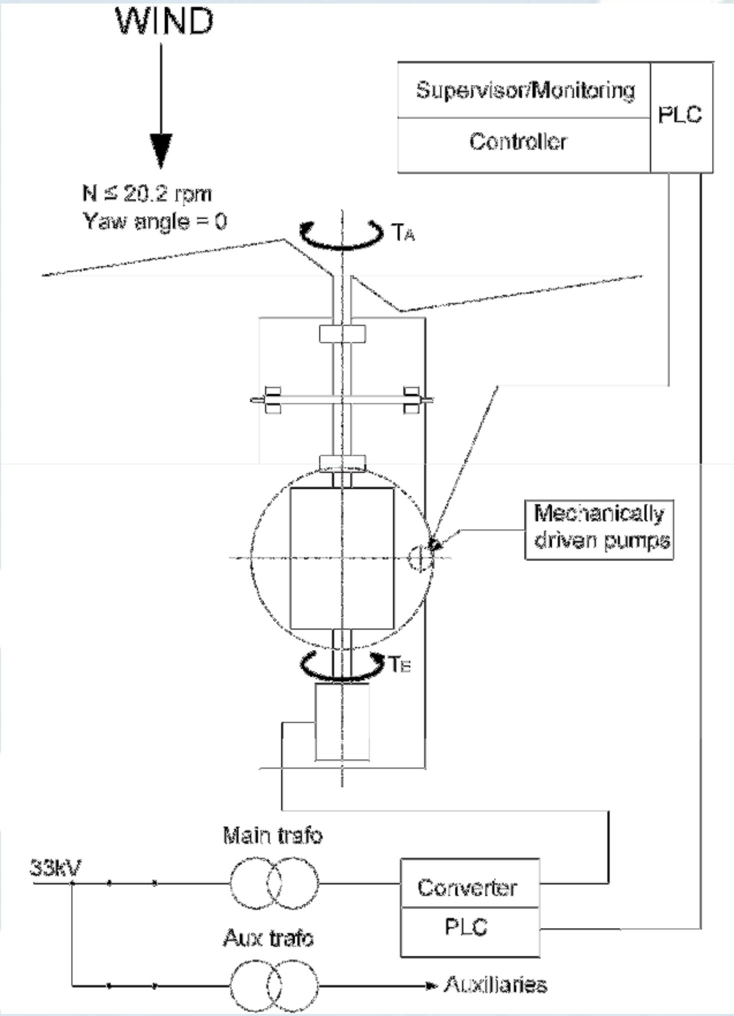
OPERATION MODALITY - START-UP INTERMEDIATE STAGE



- The rotor axis is moved CW toward the wind direction by “Yawing control loop”
- When TA>TM, the generation starts
- From now on, the restraining electrical torque is controlled by the “torque control loop” in relation to the power output

OPERATION MODALITY - START-UP FINAL STAGE

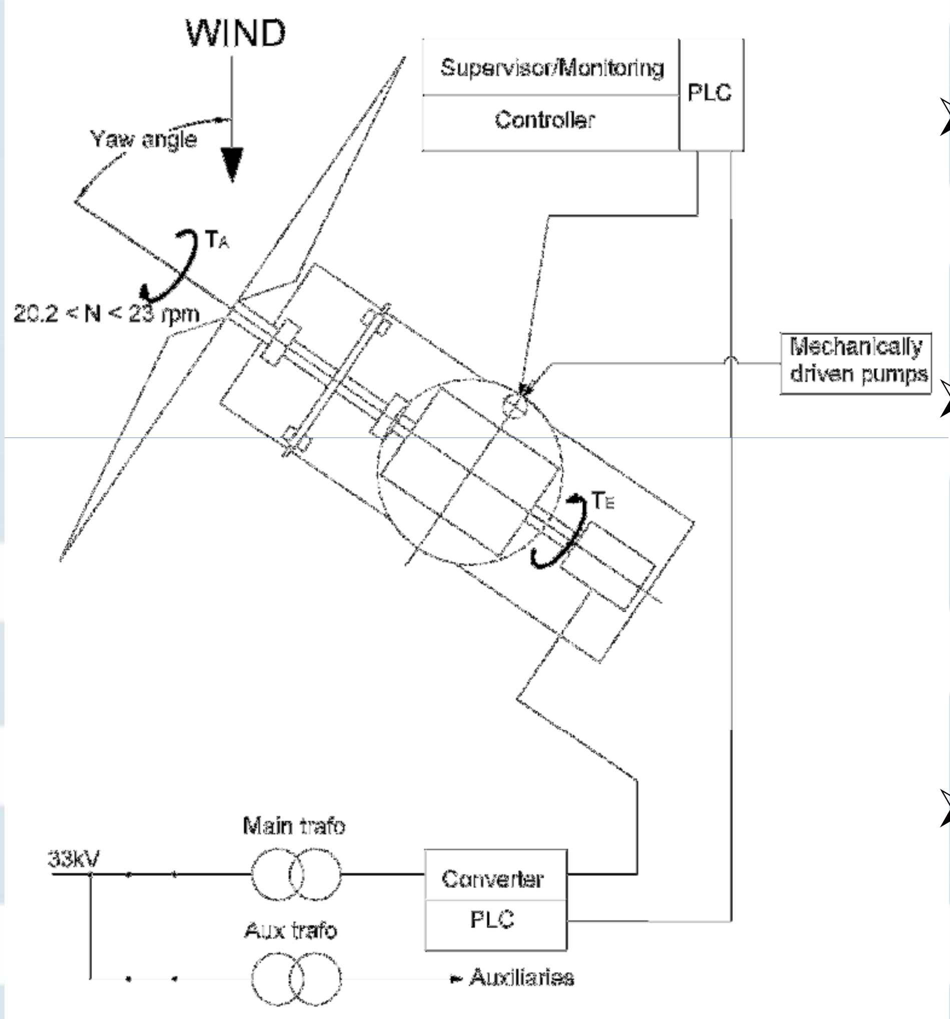
FOR WIND <12.4 M/S



- The yaw angle is reduced by the "Yaw control loop" to 0°
- The shaft is kept aligned to the wind
- The retaining electrical torque TE is modulated by the " torque control loop" versus the power to have the best λ (tip speed ratio)

OPERATION MODALITY - START-UP FINAL STAGE

FOR WIND >12.4 M/S



- The retaining electrical torque is kept by the “torque control loop” at the rated value
- The yaw angle is modulated by the “yawing control loop” to have the desired running speed in the range **19.4_20.**4 rpm, corresponding to a power output in the range 6.1_6.4 MW
- At cut out the yaw angle is 60 °

DAMAGE EQUIVALENT LOADS (DEL, FATIGUE) (AT 10^7 CYCLES)

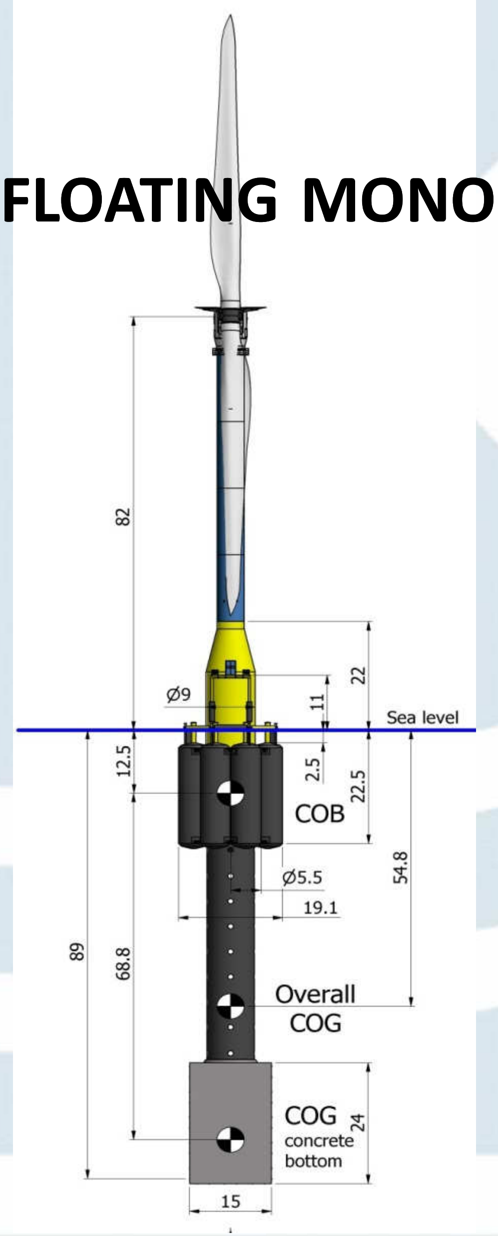
	Load Comparison. Condor 6 / equivalent 3-bladed turbines (%)
Blade root bending moment	66
Hub & Shaft torque	52
Hub lateral moments	4
Yaw torque	12
Yaw lateral moments	18
Condor 6 DEL fatigue is much lower than a 3-bladed equivalent turbine, although Condor 6 has two blades rather than three	

ULTIMATE LOADS

	Load Comparison Condor 6 / equivalent 3-bladed turbines (%)
Shaft torque	50%
Hub lateral moments	11%
Yaw moment	16%
Yaw Lateral bearing moments	50%
Blades root moments	50% once corrected the 3-bladed turbines moments to consider that physically two blades are loaded 3/2 times three blades for the same power

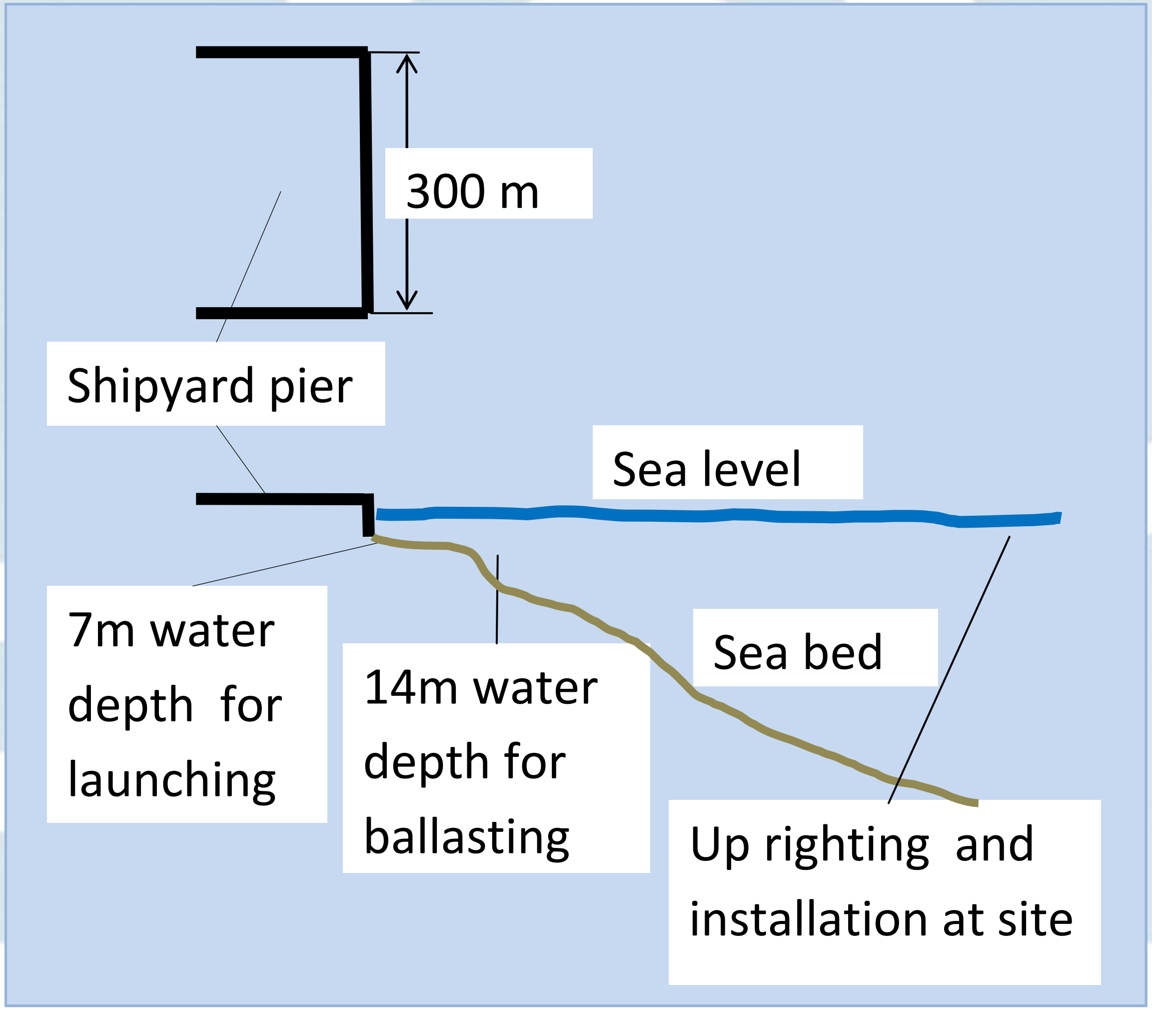
THE CONDOR 6

ON FLOATING MONO-DIMENSIONAL SUPPORT FOR DEEP WATER

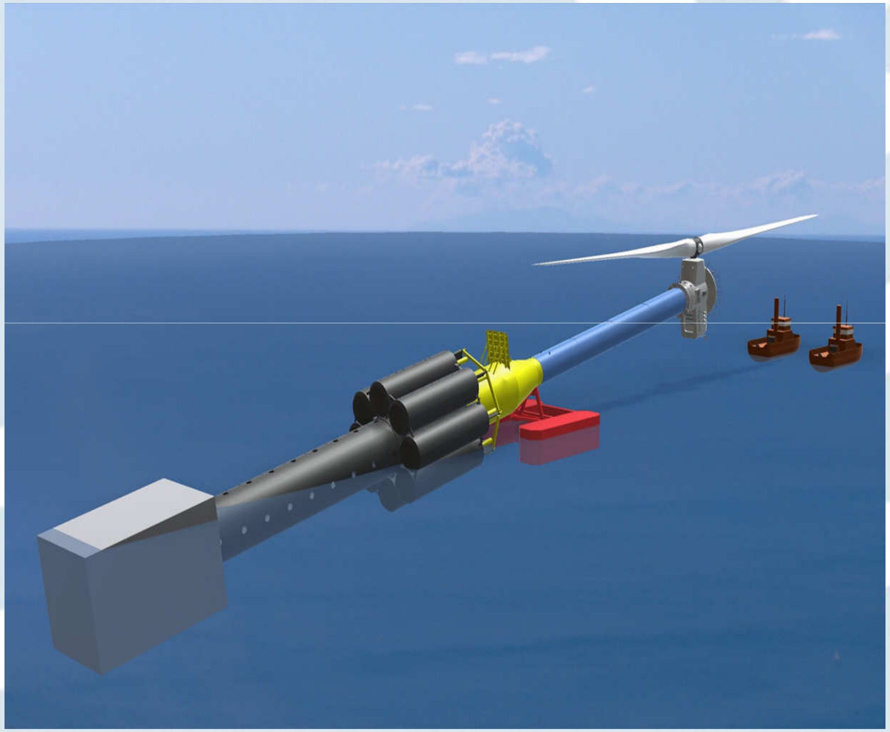


- Easy and economic to make
- Easy and economic to launch
- Easy and economic to install
- Very stable in operation with little pitch and moderate lateral displacement caused by the waves and wind actions
- Steel structure; bottom ballast

MANY SHIPYARDS ARE SUITABLE FOR LAUNCHING



TRANSPORT TO DEEP WATER SITE



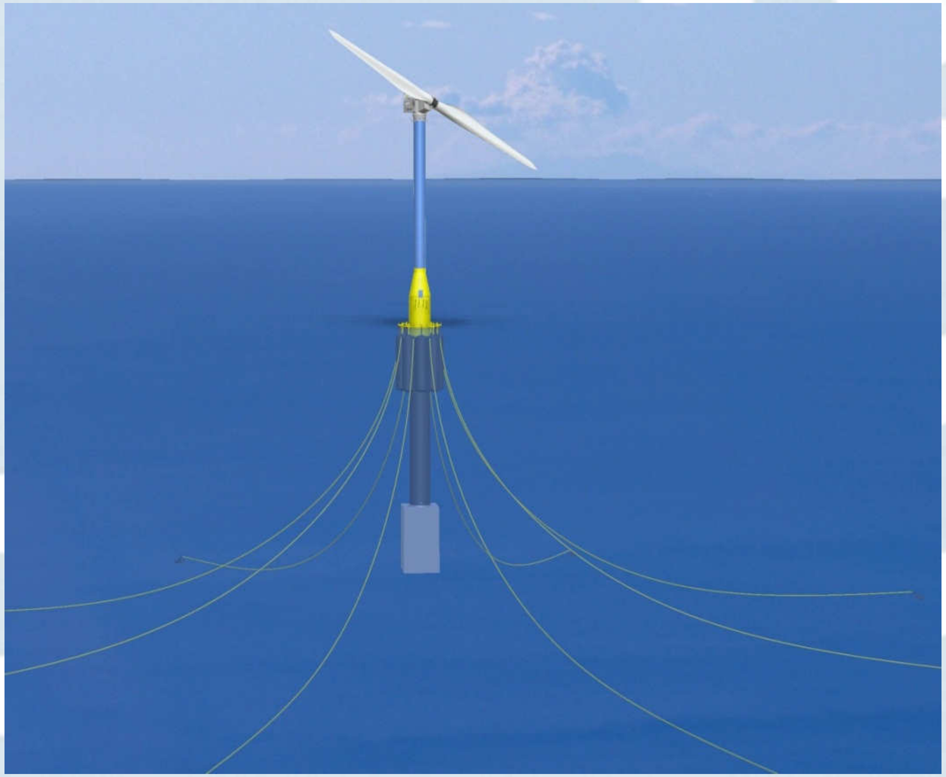
➢The image shows a Condor 6 unit being towed to an deep water installation site.

➢A barge is placed under the tower to prevent the nacelle touching water.

➢The draft is about 14 meters.

➢No heavy crane vessels are needed for transport, installation or maintenance of the Condor 6 with spar.

INSTALLATION IN DEEP WATER



- At the installation site, the unit is released and the bottom volume is completely flooded, by opening valves.

- The unit is self-uprighting.

- 8 Mooring lines are set by tugs or supply vessels acting on opposite sides placing the anchors at due distance to get the right catenary profile.

BEHAVIORS OF THE SUPPORT STRUCTURE IN OPERATION

- The center of gravity is much lower than the center of buoyancy, hence high stability in water irrespectively of the role of the mooring lines
- No risk of mooring lines breaking for slaking
- Little inclination of the tower in normal operation, non affecting the turbine performance
- No resonance support structure - waves (but forced oscillations)
- High period of natural mode of the structure around its axis, non affecting the yaw control.

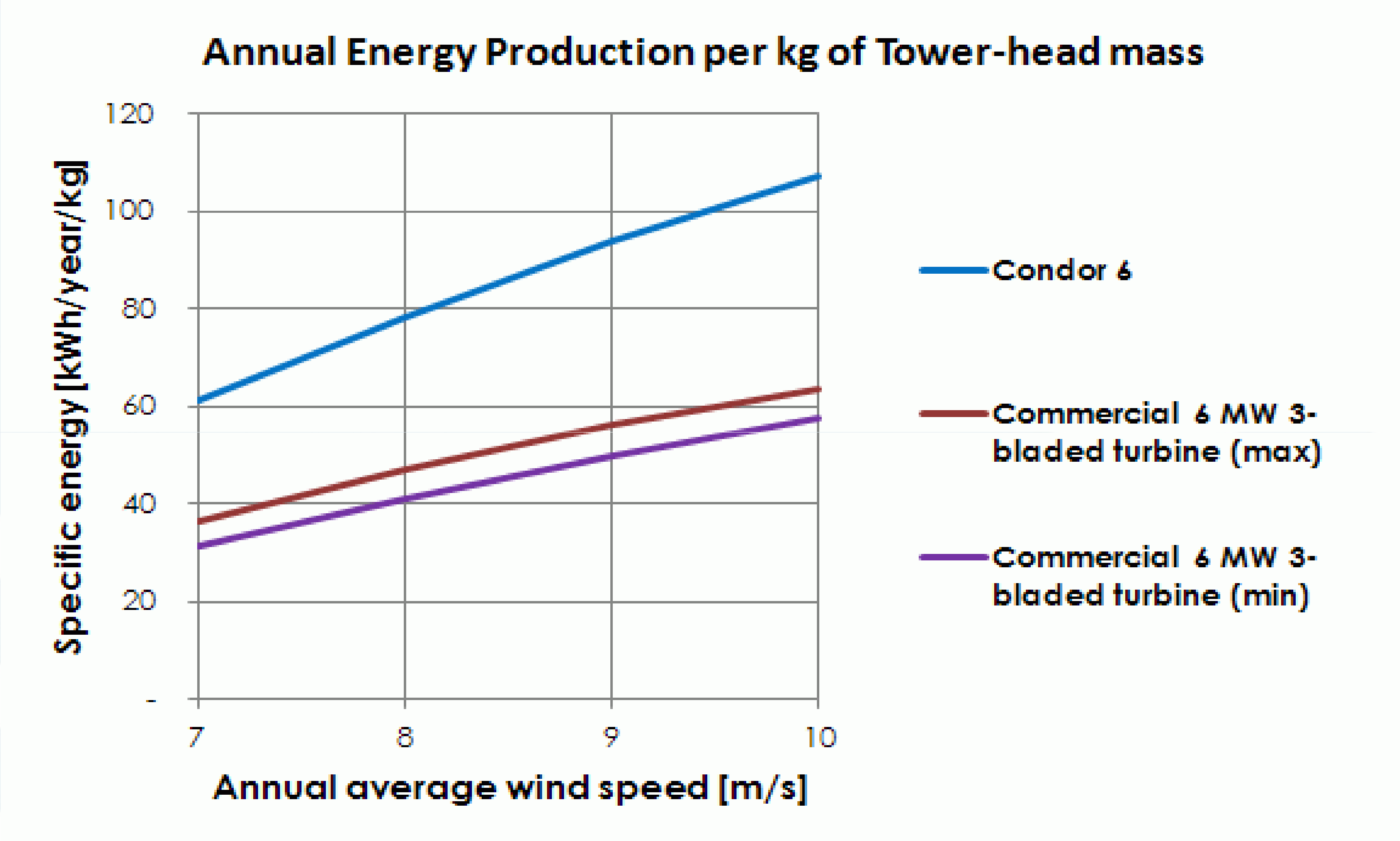
FEATURES FOR MAINTENANCE

- The Condor 6 offshore wind turbine is designed to allow all maintenance operations without heavy lifting vessels.

- Access for repair can be done via helicopter and all repair works can be carried out inside the nacelle itself.

- In case of need all heavy component, even the rotor can be moved up and down by a special elevator (patent pending).

SPECIFIC ANNUAL ENERGY PRODUCTION



CONCLUSION: TECHNOLOGY CHEAP, RELIABLE, EASY TO MAINTAIN

(in comparison with a conventional three-bladed of same size)

- **At least 30% higher specific annual energy production (kWh/year/kg)**
- **Lower Capex due**
  - Lighter turbine [250t vs. 350t Siemens new 6 MW direct drive, 500 t Areva and 550 t MHI)
  - Few moving parts
  - Easy to make support structure
- **Lower installation cost as**
  - The Unit is towed to the site fully assembled
  - No heavy marine mean is necessary
- **Good reliability and easy maintainability due**
  - Fewer fault mechanisms and use of reliable & proven components
  - Rotor and drive train subjected to lower fatigue
  - Easy access by helicopter
  - Normal maintainability feasible on board
  - Extraordinary maintainability feasible by using the maintenance elevator without large crane ships

THANK YOU VERY MUCH