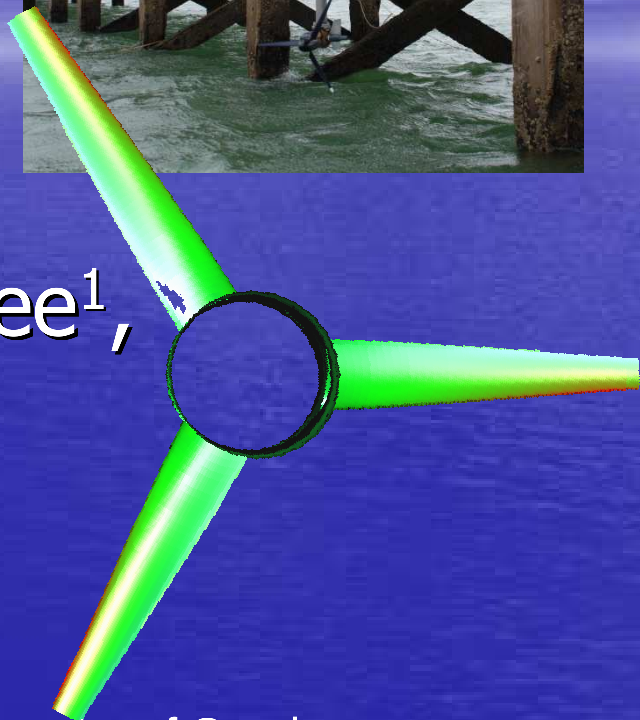
Economic viability of alternative horizontal axis tidal turbine concepts



Operation and Maintenance simplicity is the key?

SR Turnock[1], RF Nicholls-Lee[1],
R Allton[2], D McKenzie[2],
M Sharpe[3], R Rigg[3]

[1] School of Engineering Sciences (WUMTIA), University of Southampton
[2] Alstom Power Ltd, *Newbold Road, Rugby, Warwickshire*
[3] Log+1, *4 The Green, East Leake, Loughborough*

Marine Environment is

- Unforgiving…
  - Corrosion
  - Extreme loads
  - Inaccessible
  - Marine Growth
  - Salty
  - Wind, waves and currents…
  - Wet!

Electro-Mechanical design prefers
• Clean and dry
• Controlled temperature
• Easy to Access and Maintain

Challenge is to develop Cost-effective designs for Marine Renewable Systems

That can
1. Survive
2. Generate useful energy
3. Be profitable

Can available energy be harvested?

- Mount moving parts and electrical components away from sea

  offshore wind turbine

- Mount moving parts well below sea surface (reduce extreme loads)

  tidal turbines

- Mount on the sea surface

  wave energy?

dti

ECONOMIC VIABILITY OF A SIMPLE TIDAL STREAM ENERGY CAPTURE DEVICE

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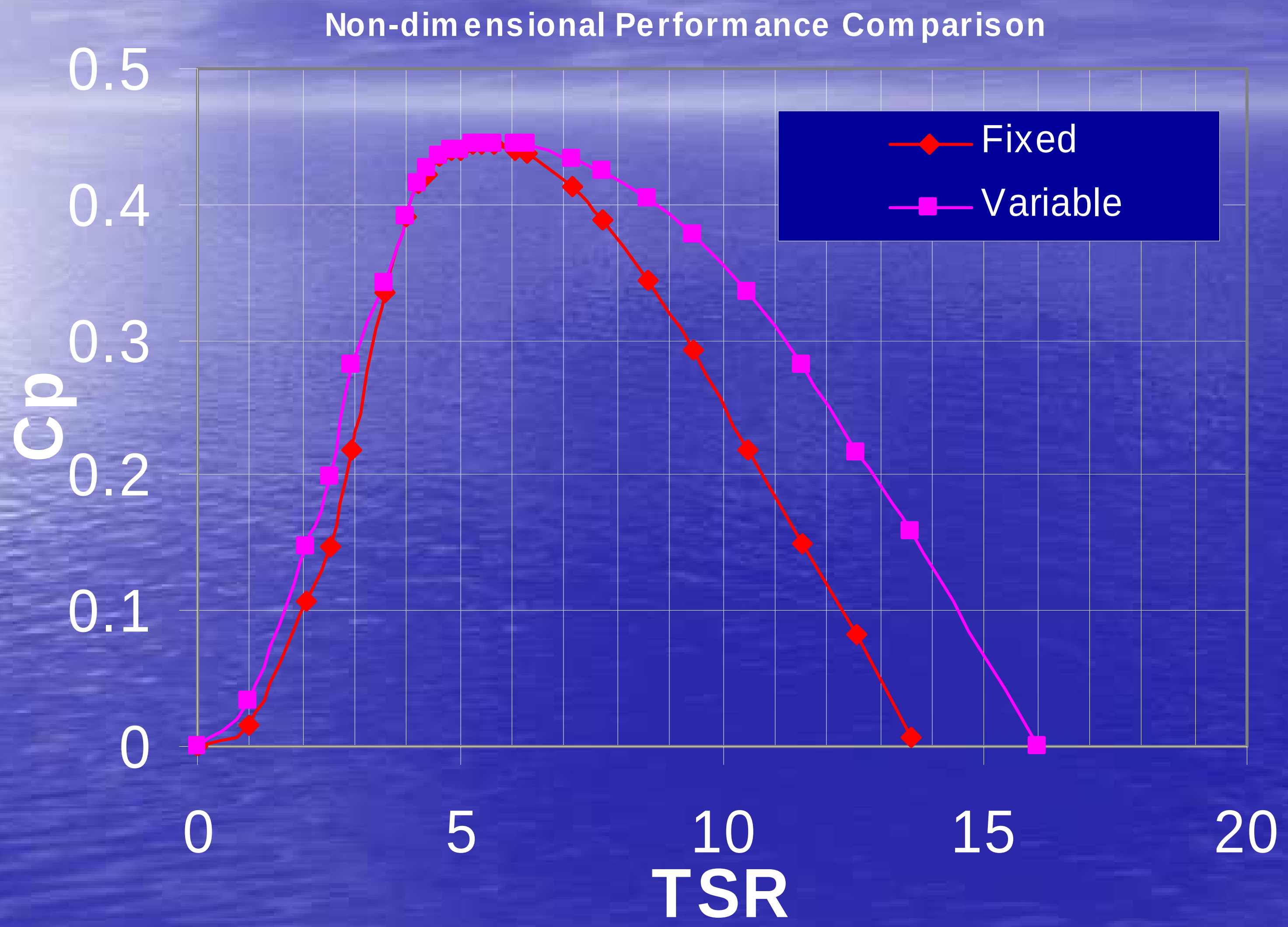
- Aim was to examined economic viability of alternative HATT designs based on simplifying mechanical design:
  - Remove ability to follow current direction
  - Remove ability to pitch blades

- Is trade-off in reduced capital cost and O&M paid-back from greater availability compensating for loss of energy capture?

Horizontal Axis Tidal Turbines

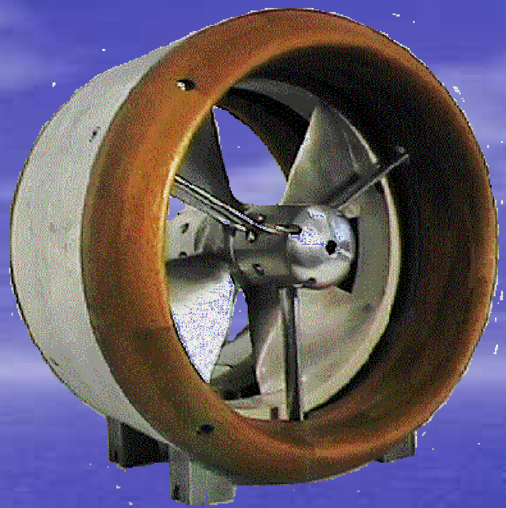


Power Capture

- TSR ≥30.0 (slow current, <0.55m/s) it is stationary for 21.4% of lunar tidal cycle and generates no power
- TSR ≥20.0 (modest current, <0.9m/s) it operates for 13.5% of time but generates 1.2% of power
- TSR ≥10.0 (reasonable current, <1.78m/s) it operates for 44.2% of time and generates 36% of power
- TSR<10.0 (high current, <2.5m/s) it operates for only 20.9% of time but generates 62.8% of total power.

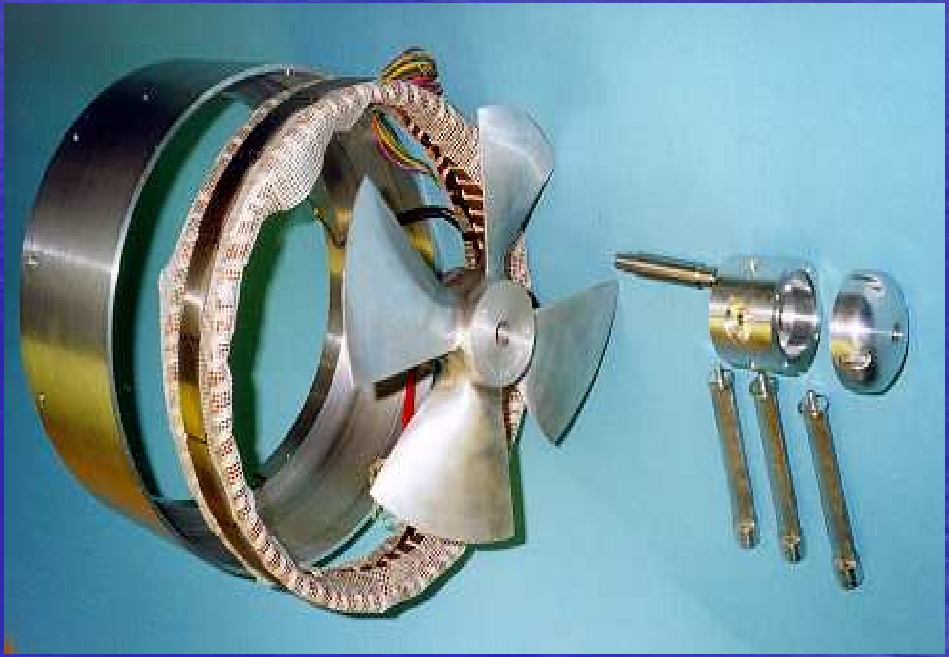
Is it better to turn turbine over all the time to reduce marine growth
or to start at high cut-in speed to reduce mechanical wear on drive train?

Effect of Yaw?



Fixed Orientation

- Well represented for off-axis flow by $\cos^3\phi$
- More important is bi-directional nature of flow
- Is it better to use section designed to operate in one direction and accept poorer performance in other, Or
- Design section to work well in both directions…



HATT Basis

- What was common?
  - Same (monopile) support structure with single turbine
  - Assumed 40m depth, 20m diameter, max tide 2.5m/s
  - Effect of local yaw negligible

Power Capture Control
– power electronics vs mechanical complexity

•Fixed Pitch blade,	Fixed RPM generator
•Fixed Pitch blade,	Variable RPM generator
•Variable Pitch Blade,	Fixed RPM
•Variable Pitch Blade,	Variable RPM

Basis of Study

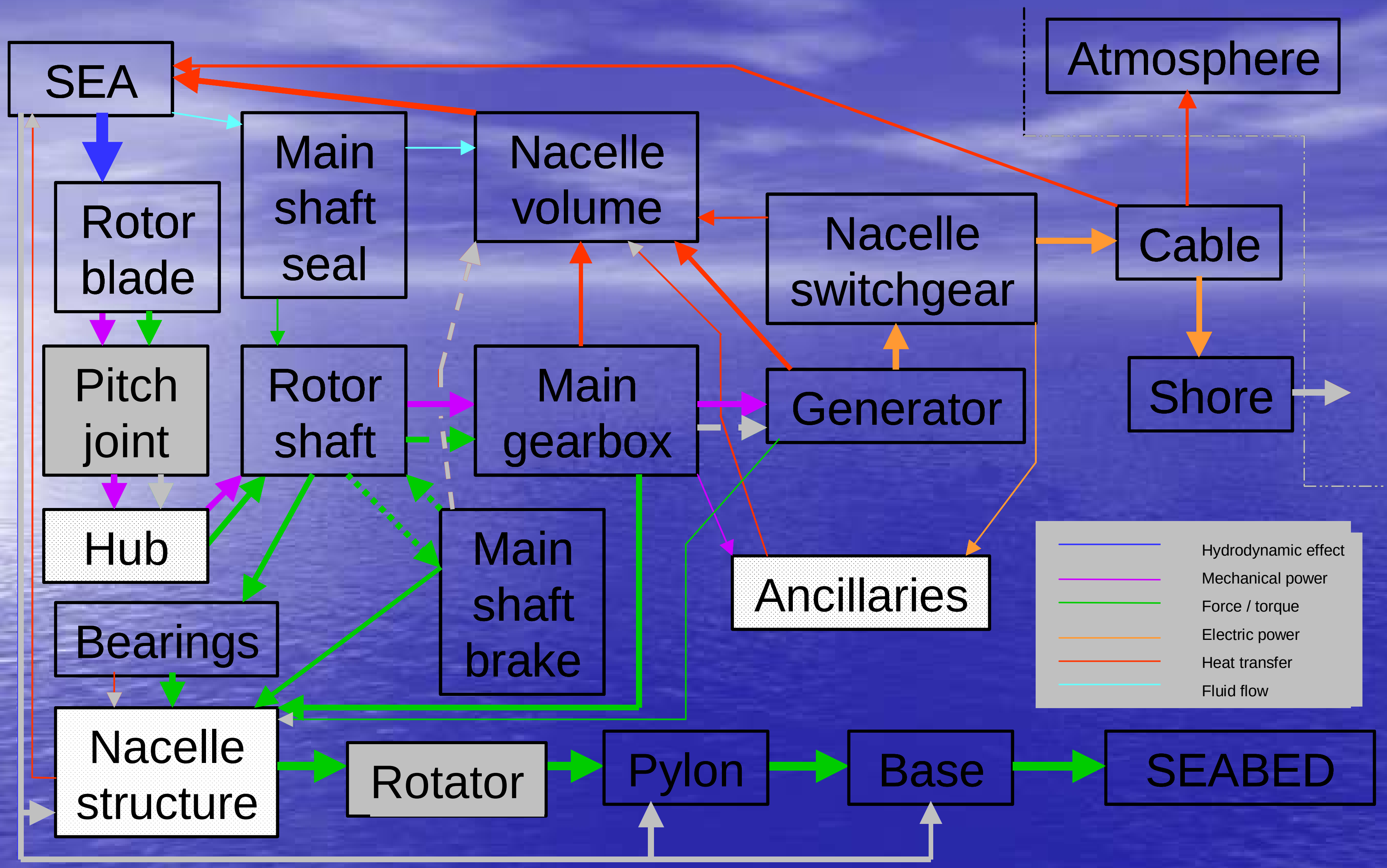
Parameter	Value	Unit
Generator rated power	1	MW
Maximum tidal current – spring tide	2.5	m/s
Ratio of peak spring tidal current speed : peak neap tidal current speed	2.0	-
Rotor diameter	20	m
Maximum nacelle diameter	4	m
Maximum nacelle length	10	m
Water depth	40	m
Number of blades	3	
Transmission voltage	33	kV
Cable distance from device to shore	5	km
Number of devices per farm	30	

Effect of pitch system/rated generator Energy per lunar month -MWh

Diameter	Rated Power +10%	BI-DIRECTIONAL DESIGN		VARIABLE PITCH DESIGN			
m, [hub/D =0.2]	MW	Fixed RPM (14.0)	Variable RPM	Fixed RPM (17.0) Variable Pitch	Variable RPM, Variable Pitch	Fixed RPM (17.0) Constant Pitch	Variable RPM Constant Pitch
20	1.1	114	160	169	177	166	177
20	0.75	90	151	158	163	156	163
20	1.25	114	161	169	178	167	177

Note: *The total capacity is taken to be the rated power over 29.4 x 24 hours. For the three rated generators of 1.14, 1.0 and 0.68 MW the energy they could have absorbed would be 0.802, 0.704, 0.481 GWh respectively.*

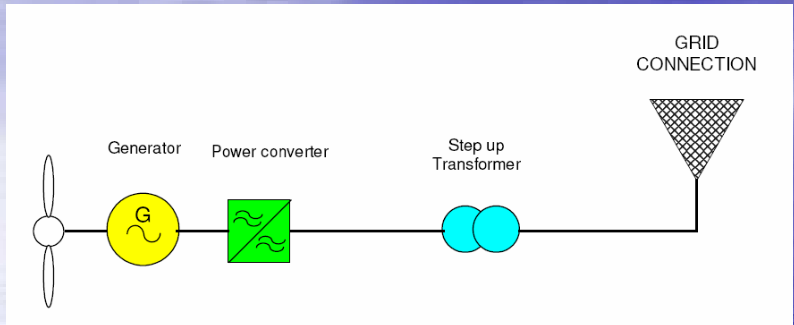
For the purposes of the economic assessment hydrodynamic capacity factors of ***23%(****bi-directional) and* ***25****%(variable pitch) based on a rated* ***1MW*** *generator capacity*

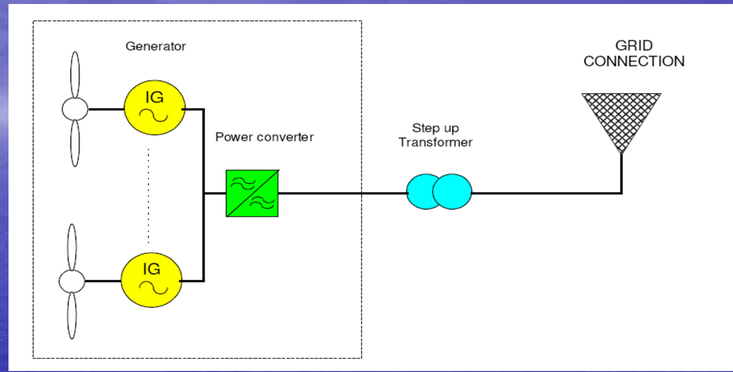


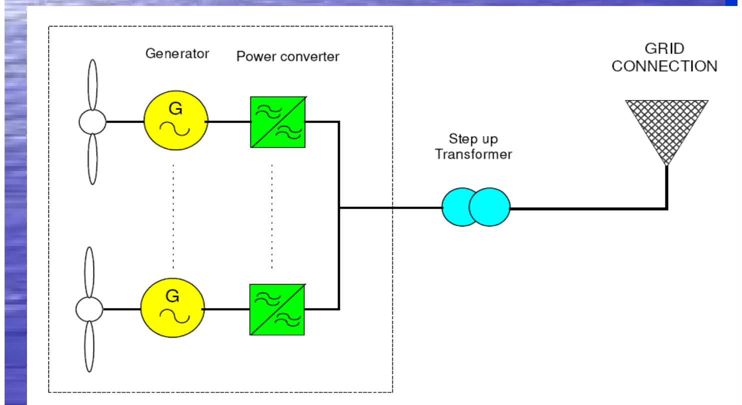
Components specific to variable pitch device

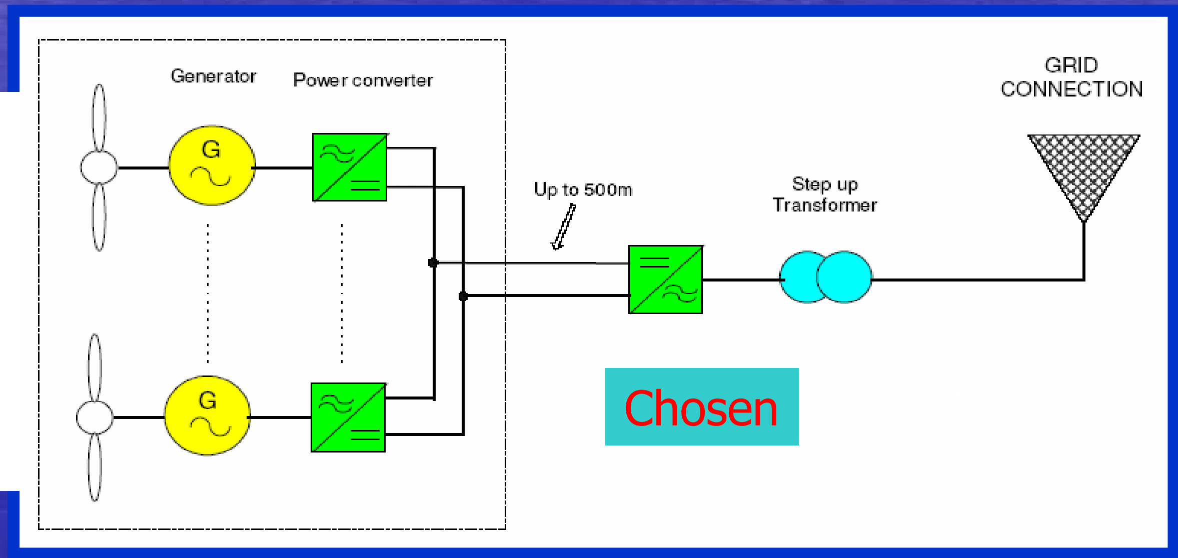
Components differing between fixed- and variable –pitch devices

Power Supply Options



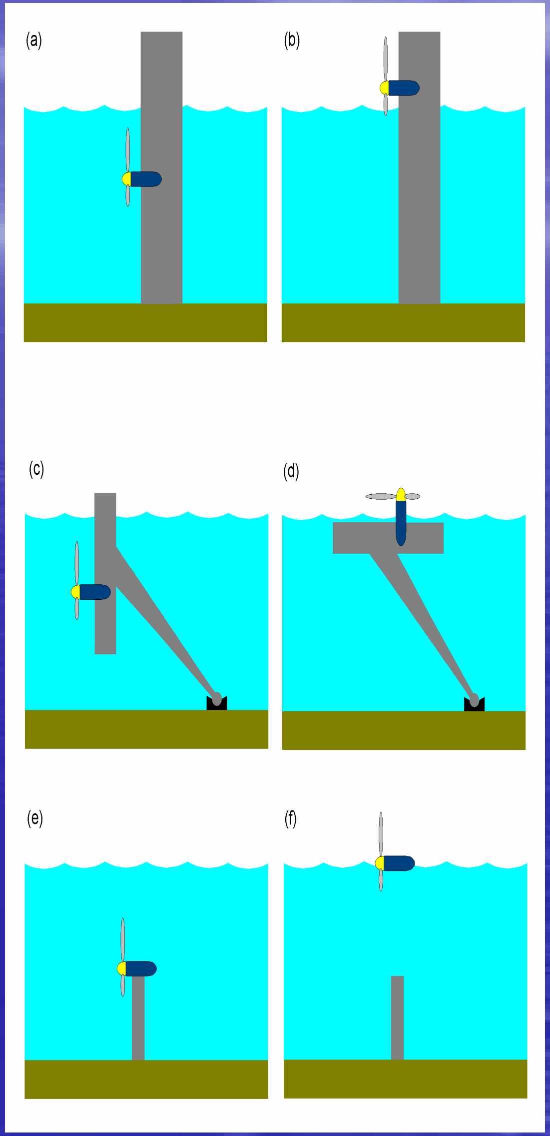


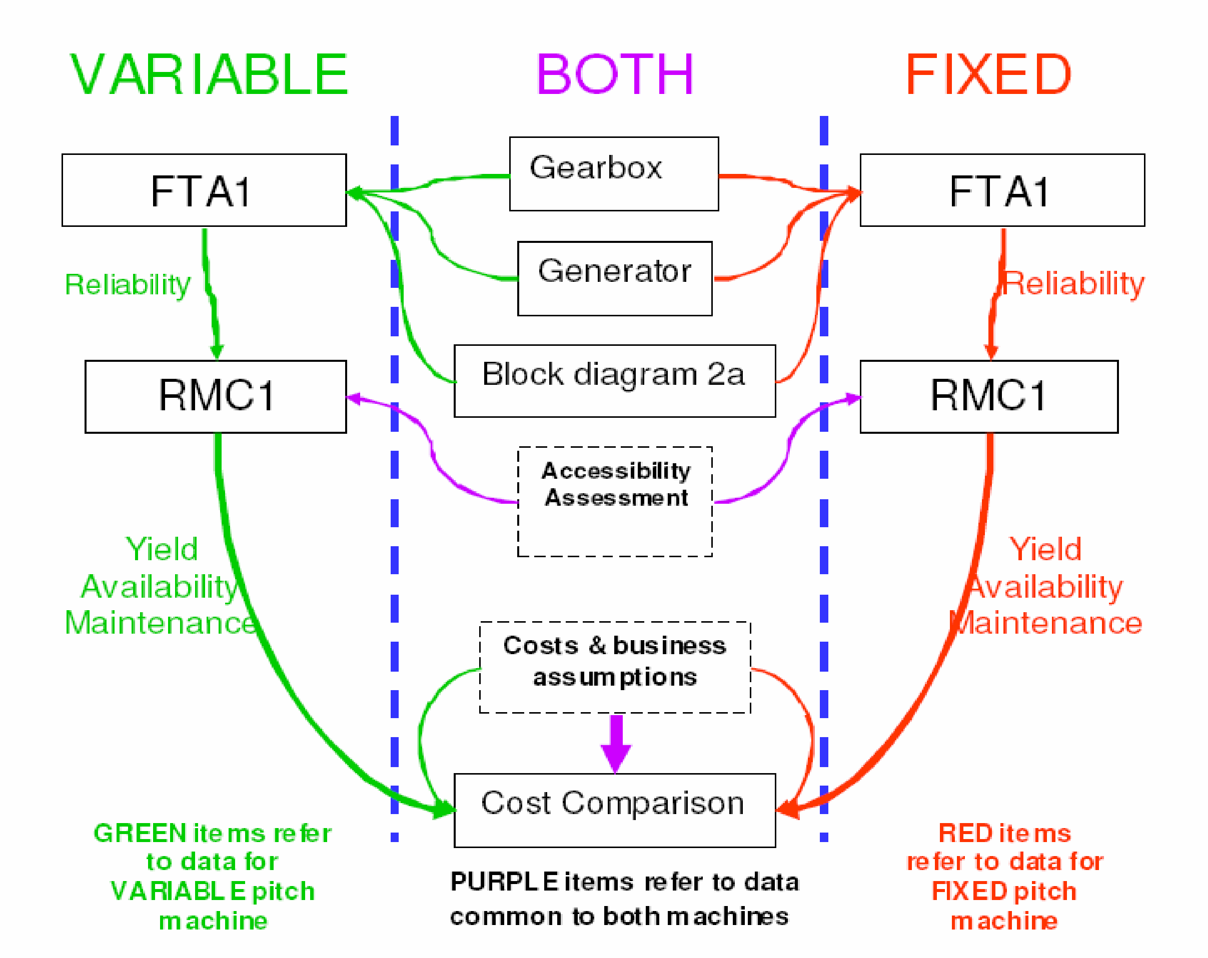




Assumptions…

- Farm scale architectures
- For farm of 30 can connect to 33kVA grid
- Remote control
- Major components in nacelle along with rotor blades all are considered as a single replacable unit





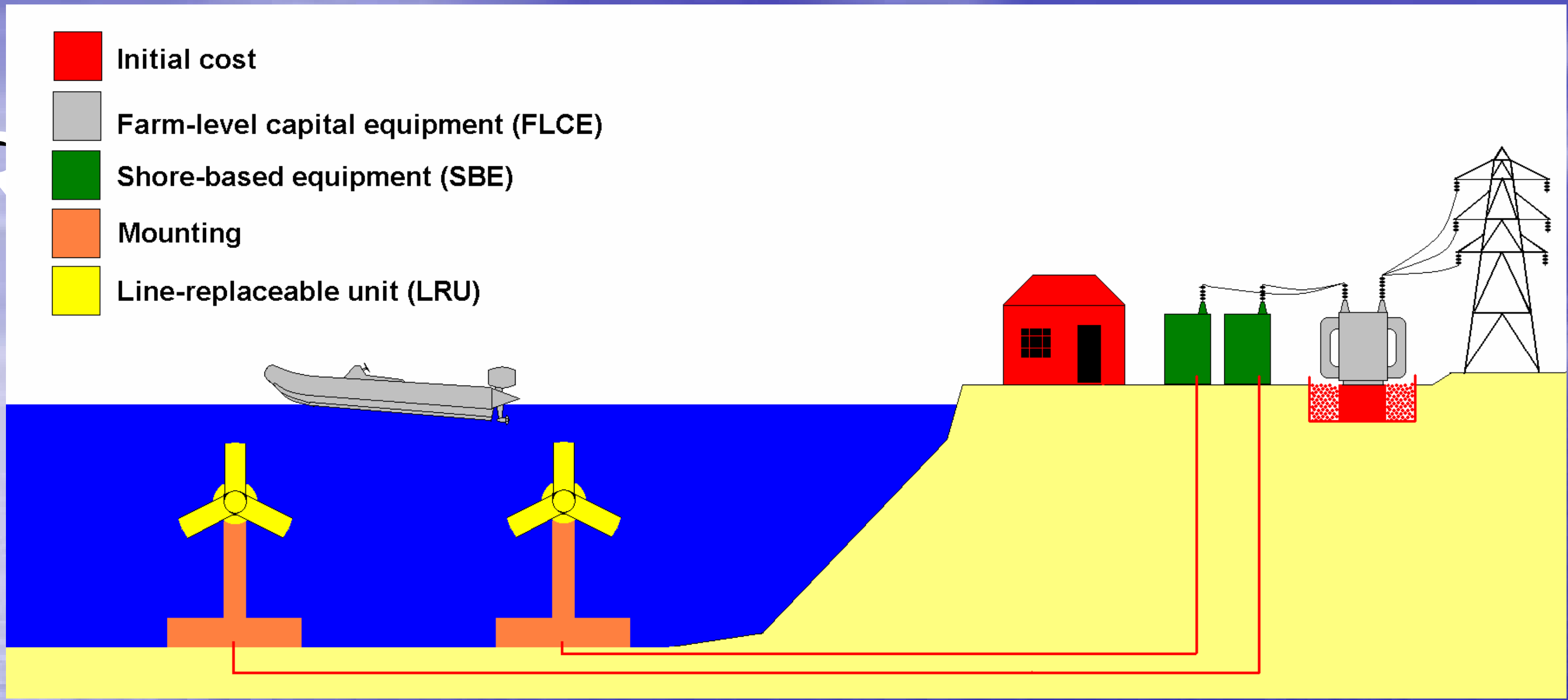
FTA

Fault Tree Analysis

RMC1

Monte carlo analysis

OREDA Data	No of failures *		Unplanned Availability	
	Fixed	Variable	Fixed	Variable
Mean	52	71	92.6%	90.1%
Max	143	194	81.1%	74.5%
Min	3	5	99.6%	99.4%



Assumptions	Units	Fixed Pitch Farm	Variable Pitch Farm
Rated Plant capacity	MW	30	30
Capacity factor	%	23	25
Plant life	Years	15*	15*
Year cost base		2006 £	2006 £
NPV discount rate		10%	10%

15 years for principal LRU life, other elements have longer assumed lives.

Cost Estimates

Cost Item		Number per farm		Farm cost	
	Cost	Fixed	Variable	Fixed	Variable
Initial set-up cost	£ 3,750,000	1	1	£ 3,750,000	£ 3,750,000
Farm Level Capital Equip,	£ 4,500,000	1	1	£ 4,500,000	£ 4,500,000
Shore Based Equip.	£ 150,000	15	15	£ 2,250,000	£ 2,250,000
Mounting - Fixed	£ 300,000	15		£ 4,500,000	
Mounting - Variable	£ 322,500		15		£ 4,837,500
Line Replacement Unit - Fixed	£ 750,000	30		£ 22,500,000	
Line Replacement Unit - Variable	£ 806,250		30		£ 24,187,500
			Total	£ 37,500,000	£ 39,525,000
			Cost/MW	£ 1,250,000	£ 1,317,500

Table 8.3 Cost estimates

Fixed pitch machine used as basis
– variable pitch estimated as 5.4% more expensive

Operation and Maintenance

Operation and Maintenance	Intervals	Fixed Pitch Total Cost (2006 £)	Variable Pitch Total Cost (2006 £)
Routine O&M (per MW/year)	p.a.	£37,500	£40,300
Major servicing	5 yrs	included in above	included in above
	as required	£24,000	£25,700
Fixed annual farm running cost	p.a.	£320,000	£320,000
Rates	p.a	included in above	included in above
De-commissioning costs, per mounting	At yr 25 after mounting commissioning	£25,000	£25,000

Table 8.4 Operation & maintenance assumptions and estimates

Cost of electricity

- Used unscheduled availabilities, hydrodynamic capacity factor, and scheduled availability of 15 years
- Mean failure rates gives 53Gwh(fixed) 55Gwh(variable). For max failure rates energy production drops by 12% and minimum increases by 8%
- Base case gives

	10 year	15 year	Range(15 years)
fixed	£119/MWh	£94/MWh	£55-150/MWh
variable	£129/MWh	£104/MWh	£55-188/MWh

Conclusions

- Variable pitch machine (10% better) produces more energy in a given period unless reliability is very low
- Fixed pitch always offers lower initial capital cost and unplanned maintenance costs
- Fixed pitch always offers lower cost per unit except if very high reliability
- Fixed pitch offers more robust design concept (within limitations of study)