Concept Evaluation for Torpedeo Wave Turbin

Assessment carried out for Innovasjon Norge rev 2014-09-12
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Short summary and recommendations

Summary:
Analysis of the proposed system show that it will be necessary to increase the blade lengths substantially in order to achieve a reasonable energy capture with the device. An example show that increasing the blade length from 1 meter to 5 meter increases the energy capture from 2.5 % to 21.7 % of the incoming energy.

Analysis using a typical near shore wave climate (Karmøy scatter diagram) gives a yearly production in the range of 150 MWh for a turbine with 5 meter long blades.

The torpedo with the two turbine blade rings, counter acting generator kept away from the active wave zone is an interesting solution and addresses issues related to extreme loads and wave energy conversion without direct contact with the waves in an elegant way.

A nice feature of the system is that it is easy to retrieve and maintain by simply disconnect and bring to shore.

It is difficult to assess the economics in the project before more detailed analysis/engineering has been carried out but given the innovative solution it is our opinion that it is worth looking into.

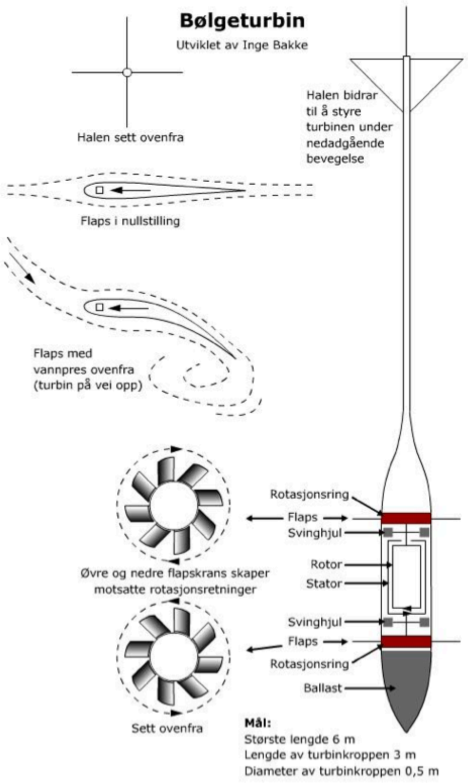
Recommendation:
If it is decided to investigate this system further it is recommended to: A) Perform a scaled model test where the blades and energy conversion can be documented. B) Analyse the merit of a counter rotating generator and C) An engineering study to design and size the complete system (including the surface buoy), and derive a reliable estimate of cost. Here the balance between size, cost and performance can be documented.

Scope of work, received information and principle for energy conversion

In an email dated 25th August 2014 Innovation Norway asked for an evaluation of a proposed wave energy converter which we have named "Torpedo Wave Energy Converter (TWEC)"

Our scope is to look at the system and do a qualitative evaluation of the system regarding potential for energy production, general feasibility, cost and its potential

This means that we will not do any detailed analysis of its structural strength or detailed evaluation of its potential wave energy extraction capability nor. We will apply our engineering know-how within this field to assess if the proposed design may have some merit as energy producer.



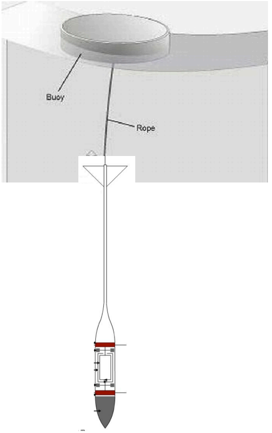
The TWEC consists of two counter rotation external turbine blades. One is connected to the stator and one is connected to the rotor hence the rotational speed on the engine is doubled.

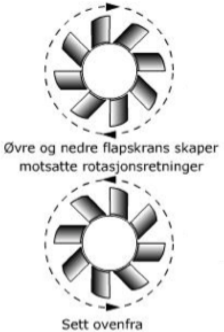
The turbine blades are soft which means that they change the profile depending on if the TWEC is moving up or down and ensures that the rotation of the rotor is kept in the same direction.

The TWEC is attached to a surface buoy that moves with the waves and the energy is therefore extracted from the vertical motion of the TWEC by the turbine blades alone. This means that it will be the size of the surface buoy, the dimensions of the turbine blades, the weight of the TWEC and the stiffness of the connecting wire between the TWEC and the surface buoy that determines the potential for energy production

Power is a function of velocity and damping force (P = F*U [N*m/s = W] and which will be analysed

Estimate of potential energy conversion





The energy input is from the buoy. I.e. the motion of the buoy, the size (area) of the buoy. The potential force is given as the Area of the buoy times the submergence and the motion and velocity is given by the wave height and wave period.

Electricity is generated by converting the vertical motion of the torpedo into rotational motion of the turbine that is is used by the generator to produce electrical energy.

The extraction of force and motion from the turbine blades is dependent on the area of the turbine blades and the resistance created by the "wing profiles" of the turbine blades.

This is a coupled system and therefore the resistance from the turbine blades will normally be equal to the force that is created by the submergence of the buoy. Therefore it is a balance between the buoy size, the turbine size and resistance, and the vertical velocity.

The incoming wave energy can be estimated as:

$$Pin = 0.5\ (Hm0)^2 * Te \quad [kW]$$

The extracted energy by the turbine is estimated as:

$$Ppr = ½ * \rho * A * V^3 * C_t * C_a$$

Where ρ – is the density of water, A is the exposed area of the turbine blades, V is the velocity of the torpedo in the water (equal to the wave motion velocity) C_t is the extraction efficiency of the turbine (0 to max 59.3 % (Betz limit)) and C_a is the generator efficiency.

The force required force acting on the surface buoy from the system, and that determines the size of the buoy is

$$Fb = Ppr / V$$

Using a scatter diagram it is now possible to assess the potential from the system

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Scatter diagram and available energy

Karmøy ScatterDiagram original

		Tm02	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
			3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Hs			**2.5**	**3.5**	**4.5**	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**10.5**	**11.5**	**12.5**	**13.5**	**14.5**	**15.5**	**16.5**	**17.5**	**Sum**
	0.5	**0.25**	0.1	6.0	7.3	2.5	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0			**16.8**
0.5	**1**	**0.75**	0.0	2.8	10.2	9.1	2.9	1.0	0.3	0.2	0.1	0.0	0.0	0.0		0.0	0.0		**26.7**
1	**1.5**	**1.25**		0.2	4.3	9.9	5.1	1.5	0.4	0.2	0.1	0.0	0.1	0.1	0.0		0.0		**21.9**
1.5	**2**	**1.75**		0.0	0.9	5.9	5.9	1.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0				**14.4**
2	**2.5**	**2.25**			0.1	2.6	4.8	1.2	0.2	0.0	0.0	0.0			0.0		0.0		**8.8**
2.5	**3**	**2.75**				0.6	3.2	0.9	0.2	0.0	0.0								**4.9**
3	**3.5**	**3.25**				0.0	1.8	0.9	0.2	0.1	0.0								**3.0**
3.5	**4**	**3.75**					0.6	0.9	0.1	0.0	0.0	0.0							**1.7**
4	**4.5**	**4.25**					0.1	0.6	0.1	0.0	0.0								**0.9**
4.5	**5**	**4.75**					0.0	0.3	0.1	0.0	0.0								**0.4**
5	**5.5**	**5.25**						0.1	0.2	0.0									**0.2**
5.5	**6**	**5.75**						0.0	0.1										**0.1**
6	**6.5**	**6.25**						0.0	0.1										**0.1**
6.5	**7**	**6.75**							0.0										**0.0**
7	**7.5**	**7.25**								0.1									**0.1**
7.5	**8**	**7.75**								0.0									**0.0**
8	**8.5**	**8.25**																	
8.5	**9**	**8.75**																	
9	**9.5**	**9.25**																	
9.5	**10**	**9.75**																	
		Sum	**0.1**	**9.0**	**22.8**	**30.6**	**24.9**	**8.9**	**2.1**	**0.7**	**0.4**	**0.1**	**0.1**	**0.1**	**0.1**	**0.0**	**0.0**		**100**

Karmøy ScatterDiagram Wave Energy available kW/m

		Tm02	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
			3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Hs			**2.5**	**3.5**	**4.5**	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**10.5**	**11.5**	**12.5**	**13.5**	**14.5**	**15.5**	**16.5**	**17.5**	
	0.5	**0.25**	0	0	0	0	0	0	0	0	0	0	0	0	1	1			**5**
0.5	**1**	**0.75**	1	1	1	2	2	2	3	3	3	4	4	4		5	5		**42**
1	**1.5**	**1.25**		3	4	5	6	7	8	9	9	10	11	12	13		15		**113**
1.5	**2**	**1.75**		6	8	10	12	13	15	17	19	20	22	24	26				**191**
2	**2.5**	**2.25**			13	16	19	22	25	28	31	34			42		48		**278**
2.5	**3**	**2.75**				24	28	33	37	42	46								**210**
3	**3.5**	**3.25**				34	40	46	52	58	64								**294**
3.5	**4**	**3.75**					53	61	69	77	85	94							**440**
4	**4.5**	**4.25**					68	78	89	99	110								**444**
4.5	**5**	**4.75**					85	98	111	124	137								**555**
5	**5.5**	**5.25**						120	136	152									**407**
5.5	**6**	**5.75**						144	163										**306**
6	**6.5**	**6.25**						170	192										**362**
6.5	**7**	**6.75**							224										**224**
7	**7.5**	**7.25**								289									**289**
7.5	**8**	**7.75**								330									**330**
8	**8.5**	**8.25**																	
8.5	**9**	**8.75**																	
9	**9.5**	**9.25**																	
9.5	**10**	**9.75**																	
		Sum	**1**	**11**	**27**	**91**	**313**	**794**	**1124**	**1228**	**505**	**162**	**38**	**41**	**82**	**6**	**69**		**4490**

In order to assess the potential we have used a scatter diagram of wave height vs wave period for a typical near shore location. The scatter diagram gives the joint probability of an wave height and a wave period occurring and the sum in the scatter diagram will be 100 %.

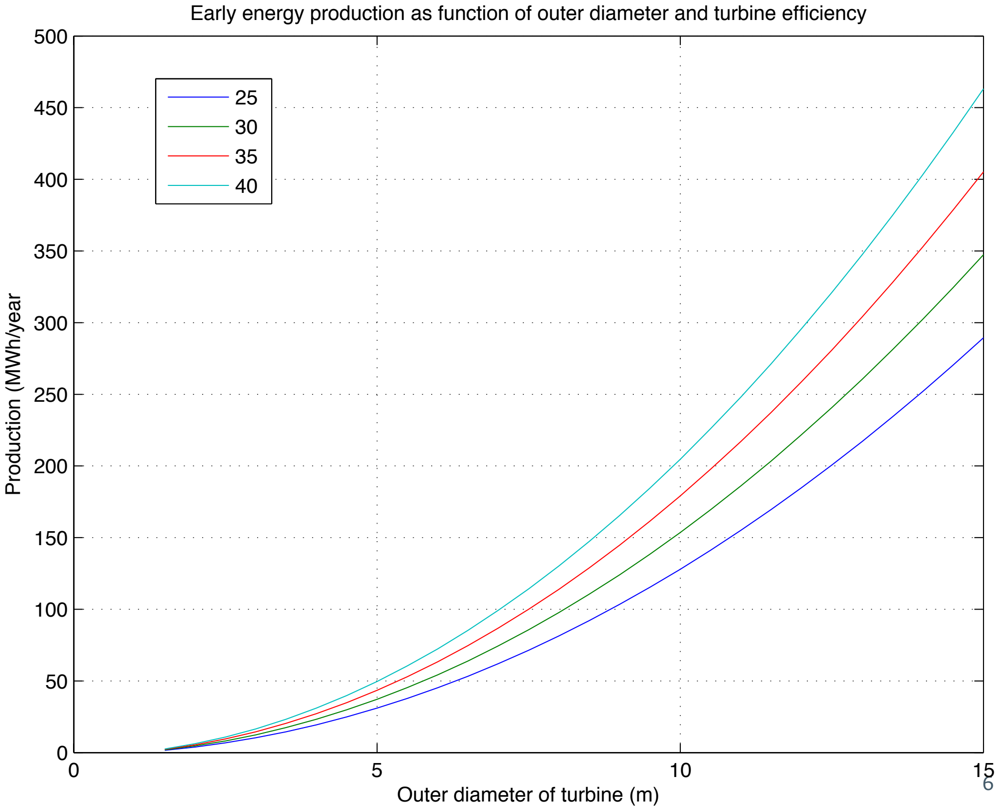
The scatter diagram on the left gives the % probability of the sea state occurring . The scatter diagram to the right, gives the wave energy for the relevant sea state. The green marks in the two scatter diagram represents the 95 %. I.e. for the left it means that 95 % of all sea states can be found in this area. For the right it means that almost 95 % of the energy is in this area. As can be seen they **are practically not overlapping:** In practice this means that for most of the time we have very little wave energy available. We will now use this data in the assessment of the system

Energy production

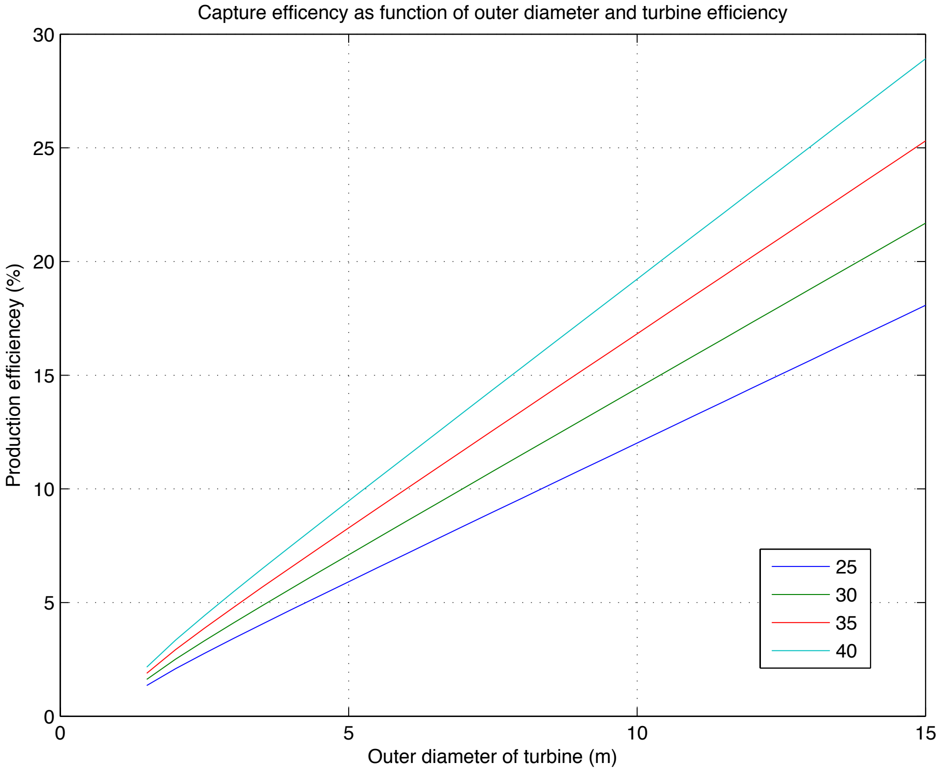
Based on the following assumptions we have estimated the possible energy production from the system:

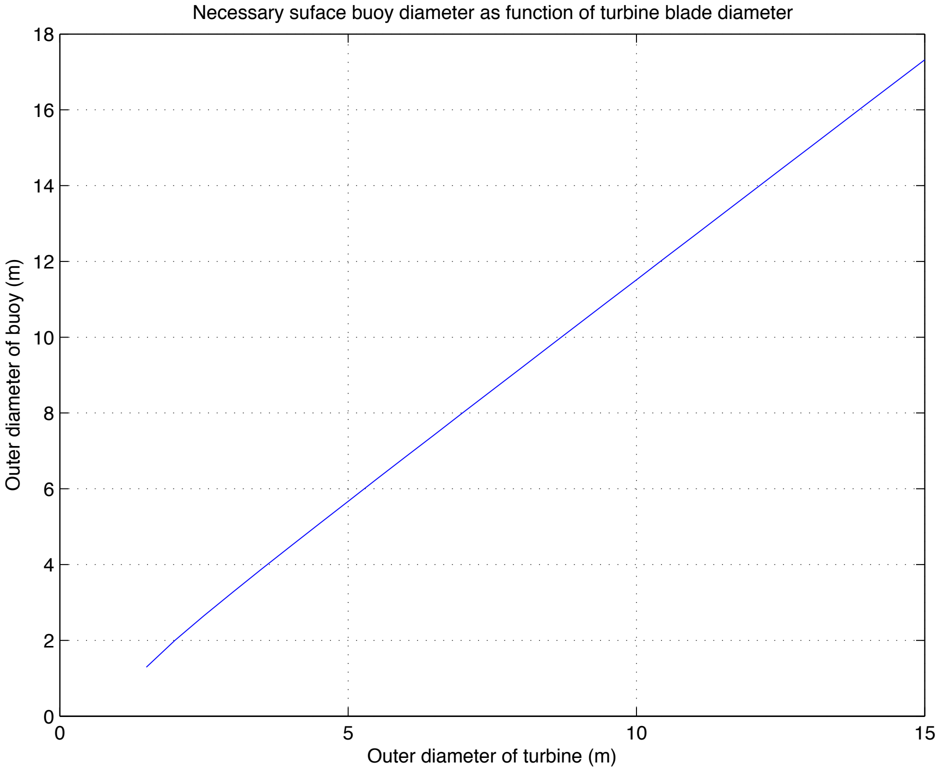
- Input is vertical velocity from the scatter diagram
- We vary the length of the blades between 1 and 7.5meters.
- Taking into account loss and conversion efficiency we vary the production efficiency in the converter between 0.25 and 0.35 (typical industry performance)

From this we estimate the total yearly production, the production efficiency in relation to the incoming energy from the waves and the necessary size of the surface buoy to be able to deliver the required energy to the converter



Production efficiency and surface buoy dimensions





Performance summary

Performance as function of turbine size					
Diameter of turbine	(m)	2	6	**10**	15
Blade length	(m)	1	3	**5**	7.5
Surface Buoy Diameter	(m)	2.0	6.8	**11.5**	17.3
Energy Capture Ratio	(%)	2.5%	8.6%	**14.4%**	21.7%
Total Yearly production	(MWh)	5	54	**154**	347
Yearly production value UK	(1000 kr)	9	109	**307**	695
Yearly production value NO	(1000 kr)	4	49	**138**	313
Income over 10 Year (UK)	(mill kr)	0.1	1.1	**3.1**	6.9
Income over 10 Year NO	(mill kr)	0.0	0.5	**1.4**	3.1

The table show the energy production, and potential earnings as a function of the turbine diameter. The surface buoy size (diameter) is derived as a function of the size of the turbine.

It is shown that the small diameter turbine indicated in the drawing and and animation received is not an ideal configuration of the system.

We see that larger the turbine blades improve the energy capture efficiency (from 2.5 % to 21.7 % in the examples shown here) and hence dramatically improves the energy production.

From the figure of energy production we see that the output is an exponential function of the turbine size. This calls for a larger turbine. The larger the better performance.

The size of the turbine will need to be balanced against the cost of the turbine which we have not been able to do in this small study. This will have to be an important part of the eventual development of the final system.

From the table we see that a turbine with blade lengths 5 meters will typically produce 154 MWh pr year in a Karmøy environment which in the UK support regime can give an income of 3.1 MNOK over a 10 year period.

In a more exposed location the production will be higher.

Comments

General comments:

The torpedo turbine solution has some very interesting features:

- The energy conversion system will be far below the active wave zone, hence it does not need to be designed for extreme waves.
- The surface buoy will be a very simple and robust structure that is easy to design to extreme conditions
- The counter rotating generator is an interesting solution as it will increase the rotation speed of the generator (and hence the efficiency without the need to include a gear system)
- The soft blades of the turbine that flex and keep the rotational direction looks interesting, but it remains to see how feasible they are if the sizes are increased. We believe that stiff blades produced in composite or Kevlar materials is probably a part of the solution. Then it is a question how efficient the shape can be made to ensure one direction rotation
- We see challenges in relation to transport of the produced energy. This will have to be through an umbilical either to surface or to the sea bed.

Energy production

- We have concluded that it is necessary to increase the diameter the turbine blades span. The energy production is a function of swept area and hence a power of 2 of the length of the blades. It is clear that the longer the blades the more energy is produced (up to a limit).
- By using he full scatter diagram and estimating the energy production as RMS from a sinus motion at the surface velocity in the given wave/period block we believe that the energy production numbers derived are relatively realistic.
- Using the 30 % generator/conversion efficiency we see that the system should be able to capture around 22% of the incoming wave energy. This is in line with what can be considered to be industry practice.