Comments on report from CMR Prototech, January 2009

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cmr Prototech

Straumekraft

Verifikasjon av landbasert minikraftverk

Kunde:
Straumekraft

Utarbeidet av:
Øyvind Torvanger

On assignment from Straumekraft AS, senior project engineer Øyvind Torvanger at CMR Prototech has computer-modeled the behavior of Straumekraft's onshore/ near-shore mini wave power plant using MathCAD. The conclusions in the report now available, are encouraging in terms of supporting Straumekraft's own preceding beliefs in the technology's survivability and power capture efficiency.

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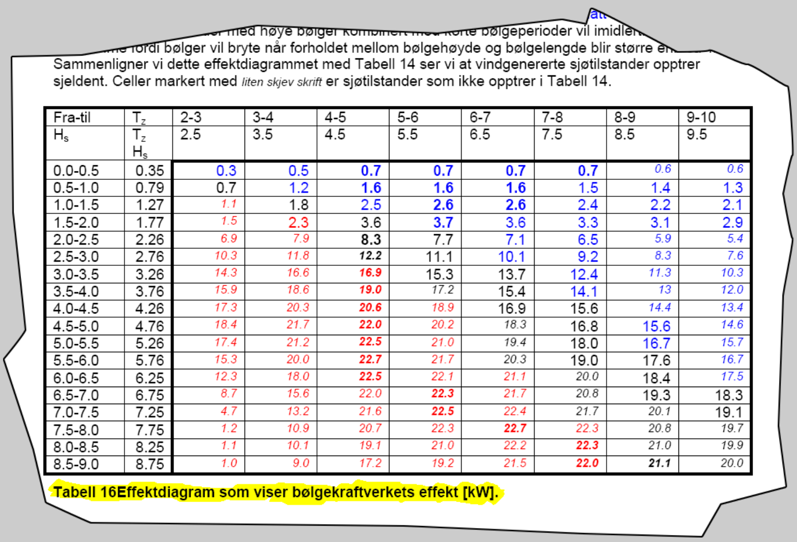
Highlighted quotes and conclusions

The report is written in Norwegian. Highlighted quotations from the CMR Prototech report with reference to the page number in the report, are presented throughout this document, with English translation in square brackets.

Page 61:



att
... med høye bølger ... bølgeperioder vil imidlert...
... fordi bølger vil bryte når forholdet mellom bølgehøyde og bølgelengde blir større en...
Sammenligner vi dette effektdiagrammet med Tabell 14 ser vi at vindgenererte sjøtilstander opptrer sjeldent. Celler markert med *liten skjev skrift* er sjøtilstander som ikke opptrer i Tabell 14.

Fra-til H_s	T_z / T_z H_s	2-3 / 2.5	3-4 / 3.5	4-5 / 4.5	5-6 / 5.5	6-7 / 6.5	7-8 / 7.5	8-9 / 8.5	9-10 / 9.5
0.0-0.5	0.35	0.3	0.5	**0.7**	**0.7**	**0.7**	**0.7**	*0.6*	*0.6*
0.5-1.0	0.79	0.7	1.2	**1.6**	**1.6**	**1.6**	1.5	1.4	1.3
1.0-1.5	1.27	*1.1*	1.8	2.5	**2.6**	**2.6**	2.4	2.2	2.1
1.5-2.0	1.77	*1.5*	2.3	3.6	**3.7**	3.6	3.3	3.1	2.9
2.0-2.5	2.26	*6.9*	*7.9*	**8.3**	7.7	7.1	6.5	*5.9*	*5.4*
2.5-3.0	2.76	*10.3*	*11.8*	***12.2***	11.1	10.1	9.2	*8.3*	*7.6*
3.0-3.5	3.26	*14.3*	*16.6*	***16.9***	15.3	13.7	12.4	*11.3*	*10.3*
3.5-4.0	3.76	*15.9*	*18.6*	***19.0***	*17.2*	15.4	14.1	*13*	*12.0*
4.0-4.5	4.26	*17.3*	*20.3*	***20.6***	*18.9*	16.9	15.6	*14.4*	*13.4*
4.5-5.0	4.76	*18.4*	*21.7*	***22.0***	*20.2*	*18.3*	16.8	15.6	*14.6*
5.0-5.5	5.26	*17.4*	*21.2*	***22.5***	*21.0*	*19.4*	18.0	16.7	*15.7*
5.5-6.0	5.76	*15.3*	*20.0*	***22.7***	*21.7*	*20.3*	19.0	17.6	*16.7*
6.0-6.5	6.25	*12.3*	*18.0*	***22.5***	*22.1*	*21.1*	*20.0*	18.4	*17.5*
6.5-7.0	6.75	*8.7*	*15.6*	*22.0*	***22.3***	*21.7*	*20.8*	19.3	18.3
7.0-7.5	7.25	*4.7*	*13.2*	*21.6*	***22.5***	*22.4*	*21.7*	*20.1*	19.1
7.5-8.0	7.75	*1.2*	*10.9*	*20.7*	*22.3*	***22.7***	*22.3*	*20.8*	*19.7*
8.0-8.5	8.25	*1.1*	*10.1*	*19.1*	*21.0*	*22.2*	***22.3***	*21.0*	*19.9*
8.5-9.0	8.75	*1.0*	*9.0*	*17.2*	*19.2*	*21.5*	***22.0***	***21.1***	*20.0*

Tabell 16Effektdiagram som viser bølgekraftverkets effekt [kW].

[*"Table 16 Power diagram showing the wave power plant's power production [kW]."*]

In the most frequently occurring sea states the plant shows a power production in the range about *7 to 20 kW* (in 2 to 5 m high waves). Given the power diagram above, Straumekraft's own internal calculations show a power production of *7 kW* on average throughout the year if the wave power plant is located at the west coast of the island of Fedje in Norway.

The plant, as assumed in the report, is a mini power plant. The float has a horizontal diameter of 5 m, and a total volume of 29.5 m³. This float is moored by a single wire rope, only 20 mm in diameter, which is responsible for propagating all the energy absorbed by the float. — This may seem flimsy for such a large float in comparison. But that's the key point about Straumekraft's wave energy concept: It has the ability to survive in extreme waves, even with thin dimensioning of the power capturing and transmitting components, which is what the computer-modeling made by CMR Prototech confirms. — In the computer model, a 25 m high, 225 m long wave is simulated, as referred in the quotation below:

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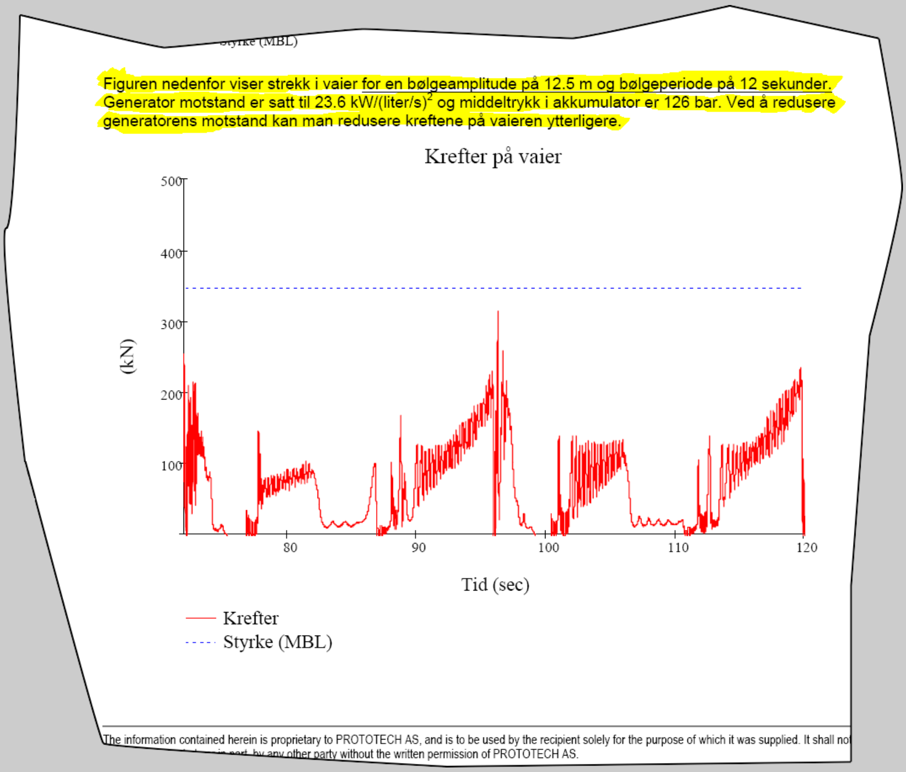
Figuren nedenfor viser strekk i vaier for en bølgeamplitude på 12.5 m og bølgeperiode på 12 sekunder. Generator motstand er satt til 23.6 kW/(liter/s)^2 og middeltrykk i akkumulator er 126 bar. Ved å redusere generatorens motstand kan man redusere kreftene på vaieren ytterligere.

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[*"The figure below shows tension in the wire for a wave amplitude of 12.5 m and wave period of 12 seconds. Generator resistance is set to 23.6 kW/(liter/s)² and mean pressure in the accumulator is 126 bar. By reducing the generator's resistance, one can reduce the forces on the wire further."*]

25 m wave height is the same as 12.5 wave amplitude. A wavelength of 225 meters is equivalent to a 12 second wave period. In addition to being extremely high, this is a very steep wave, with wave height to wave length ratio of 1/9. Maximum theoretical wave steepness is reached when wave height is 1/7 of wave length. Such a freak wave is very unlikely to occur on locations like the one assumed in the report: 30 m sea depth only 150 m from land. At about 100 meter sea depth, that wave will encounter the seabed and start to break. The diagram on the previous page shows that, even in this freak wave, the maximum tension on the wire — the red curve — will not exceed the wire's minimum breaking load — the blue dashed line.

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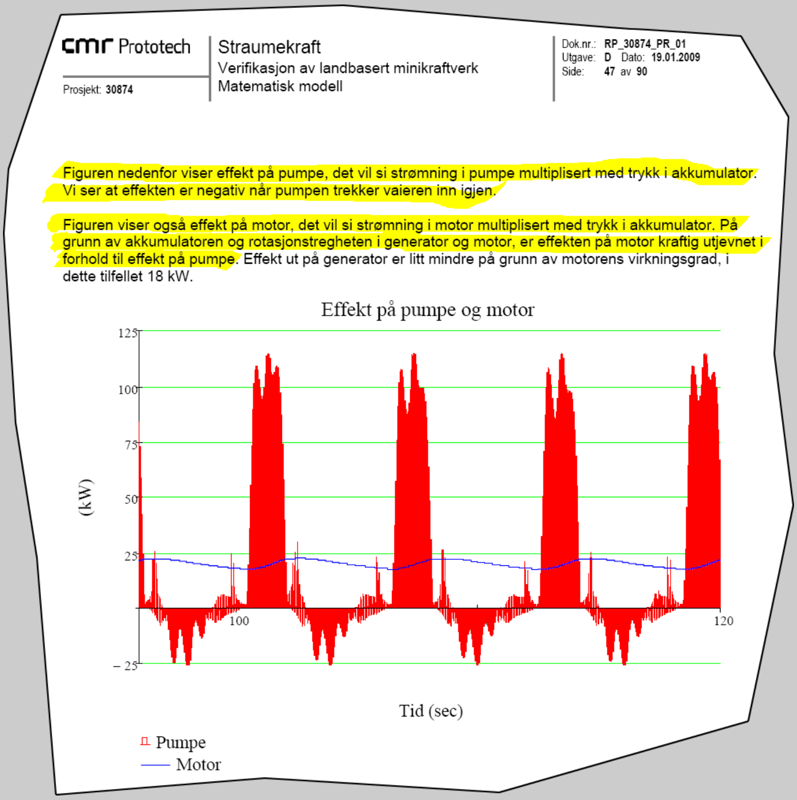

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Figuren nedenfor viser effekt på pumpe, det vil si strømning i pumpe multiplisert med trykk i akkumulator. Vi ser at effekten er negativ når pumpen trekker vaieren inn igjen.

Figuren viser også effekt på motor, det vil si strømning i motor multiplisert med trykk i akkumulator. På grunn av akkumulatoren og rotasjonstregheten i generator og motor, er effekten på motor kraftig utjevnet i forhold til effekt på pumpe. Effekt ut på generator er litt mindre på grunn av motorens virkningsgrad, i dette tilfellet 18 kW.

[*"The figure below shows throughput of power in the pump, that is, hydraulic flow of pump multiplied by pressure in accumulator. We see that power is negative when the pump pulls the wire back in.*

The figure also shows power produced by the motor, that is, hydraulic flow of motor multiplied by pressure in accumulator. Because of the accumulator and the rotational inertia of generator and motor, the power in the motor is strongly smoothed in relation to the power in the pump."]

The red graph area in the figure on page 47 in the CMR Prototech report shows power produced in a wave with wave height 2.4 m (wave amplitude 1.2 m) and wave period 6 seconds. When the graph is below zero, energy flow goes from the accumulator back into the pump, thereby spooling in the winch. We see that the net energy pumped into the accumulator is positive, with peaks around 100 kW lasting for about 1.5 seconds. (This is when the float is moved up by the wave.) The blue line is power produced by the hydraulic motor on the generator side of the accumulator. We see that the power produced here is smooth and steady at 20 kW ± 3 kW.

In the report, annual energy production is calculated, on the basis of the energy resource at a location 100 km west of Jylland in Denmark, at 31 m sea depth. See quoted table below:

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… gjort i tabellen nedenfor, hvor produksjon over 2 MWhr er markert med rødt. Vi ser at vi har størst produksjon for bølgehøyder mellom 2.0 og 2.5 m, og for bølgeperioder mellom 5 og 6 sekunder.

Fra-til H_s	T_z / T_z H_s	2-3 2.5	3-4 3.5	4-5 4.5	5-6 5.5	6-7 6.5	7-8 7.5	8-9 8.5	9-10 9.5	SUM
0.0-0.5	0.35	176	317	79	20	5	1			598
0.5-1.0	0.79	14	1864	976	245	90	24	7	3	3223
1.0-1.5	1.27		339	3496	320	65	22	15	6	4263
1.5-2.0	1.77		2	2236	1854	29	7	3	3	4134
2.0-2.5	2.26			116	**5469**	128	7			**5719**
2.5-3.0	2.76				3176	2263	9			5448
3.0-3.5	3.26				153	4303	25			4481
3.5-4.0	3.76					2927	480			3407
4.0-4.5	4.26					287	1888			2176
4.5-5.0	4.76						1294	16		1310
5.0-5.5	5.26						468	184		652
5.5-6.0	5.76						38	282		320
6.0-6.5	6.25							184		184
6.5-7.0	6.75							77	18	96
7.0-7.5	7.25								19	19
7.5-8.0	7.75									0
8.0-8.5	8.25									0
8.5-9.0	8.75									0
	SUM	190	2522	6904	**11237**	10097	4261	768	49	36029

Tabell 18Scatterdiagram som angir årlig energiproduksjon [kWhr].

Gjennomsnittlig effektproduksjon for denne lokasjonen er 36029 kWhr / (365.25·24 hr/år) = 4.1 kW. Dette gir en total virkningsgrad på 4.1 kW / (11.9 kW/m · 5 m) = **7 %** for denne lokasjonen.

[*"Table 18 Scatter diagram indicating annual energy production [kWhr].*

The average power output for this location is 36029 kWhr/(365.25 · 24 h/year) = 4.1 kW. This provides an overall rating of 4.1 kW/(11.9 kW/m · 5 m) = 7% for this location."]

From the power diagram on page 61, "tabell 16", in the CMR Prototech report, one can estimate that the optimum generator size to be employed with the plant, is somewhere between 15 and 20 kW, depending on where the plant is to be installed. A larger generator than that, would incur more costs than benefits from increased energy production, because the sea states in which the hydraulic power absorption and conversion system is capable of producing more than 20 kW, are very rare. At Fedje, those sea states occur only about 90 hours per year (1% of the time of a year). Consequently the plant is best served by having a rated generator capacity of 15 – 20 kW.

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8: Diskusjon

8.1 Sentrifugalkobling

Simuleringene viser tydelig at sentrifugalkoblingen er meget viktig for bølgekraftverkets overlevelses-evne. Sentrifugalkoblingen sørger for at pumpen ikke får for høyt turtall, men også at kreftene i vaier ikke blir for store, selv ved ekstreme bølgehøyder. Sentrifugalkoblingens karakteristikk er vist i figur nedenfor. X-aksen representerer forholdet mellom pumpens hastighet og pumpens kritiske hastighet. Y-aksen representerer last på sentrifugalkoblingen, (gitt som trykk i akkumulator). Mellom de to grafene slurer koblingen.

Optimaliseringen av giring er et resultat av formen på denne karakteristikken. Sentrifugalkoblingen slurer allerede ved bølgeamplituder på 1.2 m, se Tabell 12. Sluring og frikobling representerer tapt energi (og dessuten mekanisk slitasje, og er derfor ikke positivt for energiproduksjon. Det ville vært mulig å øke motstanden i sentrifugalkoblingen og samtidig lagt inn en sikkerhetsventil på akkumulatoren. Dette ville endret optimal giring, men ville trolig vært positivt for energiproduksjonen. Sikkerhetsventilen ville sørget for at kreftene på vaier ikke ble for høye, og også at akkumulator og motor ikke ble overbelastet.

[*"The simulations show clearly that the centrifugal coupling is very important for the survivability of the wave power plant. The centrifugal coupling ensures that the number of revolutions per time unit in the pump does not get too high, and that the forces on the wire don't get too large, even at extreme wave heights. (...)*

(...) It would be possible to increase resistance in the centrifugal coupling and at the same time add a safety valve on the accumulator. This would change optimal gearing, but in a way that is likely be positive for the energy produced. The safety valve would ensure that the forces on the wire didn't get too high, and also that the accumulator and the motor were not overloaded."]

The CMR Prototech report confirms that the centrifugal coupling (also named "speed-limiter" by Straumekraft) is a key component which ensures that the plant survives in extreme waves.

The table on the next page is compiled by Straumekraft, based on wave data from the Troll A platform in the North Sea (2005-2007) and table 16 on page 61 in the CMR Prototech report. The table shows estimated annual energy production for a wave power plant deployed on the west coast of Fedje. Values above 20 kW in table 16 in the CMR Prototech report were truncated to 20 kW, before each cell was calculated. Numbers refer to kWh/year.

H_s [m]	T_z [sec.]								
	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	Sum
0,0-0,5			2	39	44	11	5	10	110
0,5-1,0			21	482	605	149	15	4	1 275
1,0-1,5			63	926	1 365	545	86	13	2 996
1,5-2,0			32	1 058	1 645	756	183	32	3 706
2,0-2,5				1 548	2 698	1 606	484	92	6 427
2,5-3,0				1 277	3 414	2 668	681	167	8 206
3,0-3,5				796	3 439	3 199	904	340	8 677
3,5-4,0				344	2 818	3 314	1 196	312	7 984
4,0-4,5				113	1 555	2 636	1 382	308	5 995
4,5-5,0				20	1 135	2 150	1 232	321	4 859
5,0-5,5					427	1 566	1 369	440	3 802
5,5-6,0					220	893	950	384	2 448
6,0-6,5					180	680	773	420	2 053
6,5-7,0					20	360	521	201	1 102
7,0-7,5						260	420	172	852
7,5-8,0						60	140	177	377
8,0-8,5						20	80	159	259
8,5-9,0							80	300	380
Sum	0	0	118	6 601	19 564	20 872	10 502	3 852	61 509

A total energy production of 61 509 kWh/year covers the energy consumption for three households. The key figures listed below, gives an indication of the size and dimensioning needs of the current mini wave power plant. Although accurate cost estimates have yet to be done, this provides a foundation for an optimistic view on the possibilities of profitability.

Float size (diameter):	*5 m*
Float height:	*1.5 m*
Total float volume:	*29.5 m³*
Wire diameter:	*20 mm*
Minimum breaking load, wire:	*345.6 kN (equiv. to 35.2 tonnes)*
Winch drum diameter:	*400 mm*
Gear ratio, winch axle - pump, positive rotation:	*20*
Gear ratio, winch axle - pump, negative rotation:	*3.2*
Pump displacement:	*500 cm³/revolution*
Maximum pump speed:	*1450 rpm*
Accumulator volume:	*200 liters*
Hydraulic power-take-of motor displacement:	*22 cm³/revolution*
Rated generator power:	*20 kW*
Maximum generator resistance:	*30 kW/(liters/s)²*

Finally the report states that there are ways to optimize the system to produce more energy, and also that the size of the float may be reduced without reducing energy capture efficiency.

In this lies the potential for further research and increased energy-cost-efficiency.

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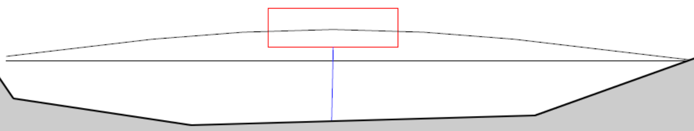
8.2 Muligheter for økning av effektopptak

Tidligere simuleringer viste at det å bruke et svinghjul på pumpen økte energiproduksjon. Tregheten i svinghjulet medførte at kreftene på flytelegemet økte, fordi massen av svinghjulet også måtte akselereres. Dette gjorde at flytelegemet lå dypere i sjøen i større del av bølgeperioden, og energi tilført flytelegemet økte. Ulempen med svinghjulet var at vaier ble overbelastet ved for høye bølger.

Et alternativ til svinghjulet kunne være å bruke en mekanisk brems på vinsj, eventuelt en ventil på hydraulikken, for å oppnå samme effekten. Bremsen må i så fall opereres på en slik måte at man ikke risikerer å redusere bølgekraftverkets overlevelses-evne.

Størrelsen på flytelegemet er også viktig. En økning på diameteren ville gi generelt økte dimensjoner på resten av anlegget og tilsvarende økt energiproduksjon. Begrensningen ligger i at flytelegemets diameter må være en del mindre enn bølgelengdene. Vi ser av Tabell 11 og Figur 8-2 at høyden på flytelegemet kunne vært redusert litt, i hvert fall for optimalisering mot en bølgeamplitude på 1.2 m.



[*"8.2 Possibilities for increase of power absorption*

Previous simulations showed that using a flywheel on the pump increased energy production. The flywheel's inertia meant that forces acting upon the floating body increased, because the mass of the flywheel also had to be accelerated. This meant that the floating body was lying deeper in the water in a longer part of the wave period, and that energy transferred to the floating body increased. The disadvantage of the flywheel was that the wire was overloaded if the waves were too high.

An alternative to the flywheel could be to use a mechanical brake on the winch, or a valve on the hydraulic system, to achieve the same effect."]