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RESEARCH AND DEVELOPMENT IN OCEAN-WAVE ENERGY IN NORWAY

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ABSTRACT

Wave-energy research in Norway started in the 1970s, and has been supported by governmental sponsorship since 1978. The wave energy resource has been studied by measurement of waves since the 1970s and by using wind data, also from previous decades, in combination with hindcasting methods. After some years of theoretical studies several proposals for wave energy converters were assessed around 1980. One proposal was a shore-based horizontal tapered channel which converts wave energy focused by means of submerged lens structures. Others were oscillating water columns in bottom-standing structures and phase-controlled power buoys of the point-absorber class. In 1985 two different full-scale shore-based converter units were constructed on the Norwegian west coast. One of them, a converter of the type with an oscillating water column and an air turbine, was partly destroyed in a heavy storm after four years of operation. The remaining unit, a converter of the type with horizontal tapered channel, water reservoir and water turbine, is at present being reconstructed according to a modified design. Research continues on optimally controlled point absorbers, including a heaving buoy as well as a twin oscillating water column. Also other wave-energy related research projects are being pursued in Norway, for instance application of wave energy for propulsion of vessels. Although wave energy is already commercial for some special purposes, much more research and development are needed to advance wave energy technology to a level where it can be used commercially for general energy supply in industrialised countries.

1. INTRODUCTION

In Norway theoretical studies on wave-energy (WE) conversion were started in the early 1970s, by interested physicists at the Central Institute for Industrial Research (SI), Oslo [1], and at the University of Trondheim, Norwegian Institute of Technology (NTH), Division of Experimental Physics [2]. A substantial research program on developing WE converters was started in Norway after 1977 with financial support from the Ministry of Petroleum and Energy. The annual grants were largest in 1979 and 1980. During the 15 years 1978-1992 the grants amounted to a total of 59, 28 and 18 million NOK for the first, second and third five-year period, respectively. (These nominal amounts are not inflation corrected. At present 1 NOK ≈ 16 ¥ ≈ 0.14 US$).

The Norwegian WE resource was assessed [3] [4]. Further, on basis of the previous theoretical studies three particular proposals for WE converters were selected in 1980 for extensive design studies and economical assessments [5]. Later, with 50 percent private and 50 percent governmental funding, two shore-based full-scale wave-energy converters were constructed in 1985 on the North Sea coast of Norway [6], at a location Toftestallen 40 km northwest from Bergen.

In the present paper we shall give a general review of the Norwegian wave energy research, however, with emphasis on our own work. Finally, the prospects for future development of WE utilisation will be discussed.

2. WAVE ENERGY RESOURCE

Following some preliminary investigations of the Norwegian WE resource [7] [8], a more extensive study was carried out. Measurement of ocean waves started in the 1970s. Further, using hindcasting models and meteorological data since 1955, a quantitative study of the Norwegian wave power resource was made a decade ago [4]. Among the research institutions taking part in early wave resource studies were NHL (Norwegian Hydrotechnical Laboratory), Det norske Veritas, NMI (Norwegian Meteorological Institute), IKU (Continental Shelf and Petroleum Technology Research Institute) and NTH (Norwegian Institute of Technology).

In recent years the company OCEANOR (Oceanographic Company of Norway) has played an active role in this work. Wave climate can now be assessed over any region of the world's oceans, to an accuracy not previously available from global wave atlas compilations from visual ship observations, using Oceanor's Global Analysis System for Ocean Waves. The system compiles wave statistics from a number of sources including global satellite altimetry, global wave model hindcasts and local shallow water wave modelling [9]. In addition, wave and other environmental measurements are also carried out worldwide by Oceanor from its base in Norway.

During the last decade, wave hindcasting models have been improved. In addition, wave measurements have been extended both to new locations and to inclusion of directional wave measurements. Measurements taken in eight offshore locations, whose positions are indicated in figure 1, have been used to calibrate the hindcast model. This model in combination with the wave measurements has improved our knowledge on the wave climate, such as information on wave direction, on duration of wave states, on seasonal variations, and on the variation of annual averages [10]. It should be noted that the WE resource off the Norwegian coast, as indicated by the numbers on the map of figure 1, agree fairly well with previous results [4] for the northern part of the coast. However, south of 63° N the updated figures are smaller, by a factor of almost 2.

During the last five winters there has been a dramatic increase in storm frequency. As a result the average significant wave height for the last five winter seasons is 20 to 40 percent larger than the corresponding previous average on the Norwegian continental shelf [11]. This is an illustration of the decadal variation of the wave climate. If wave data from the last years had been included, there would have been somewhat larger WE figures on the map in figure 1.

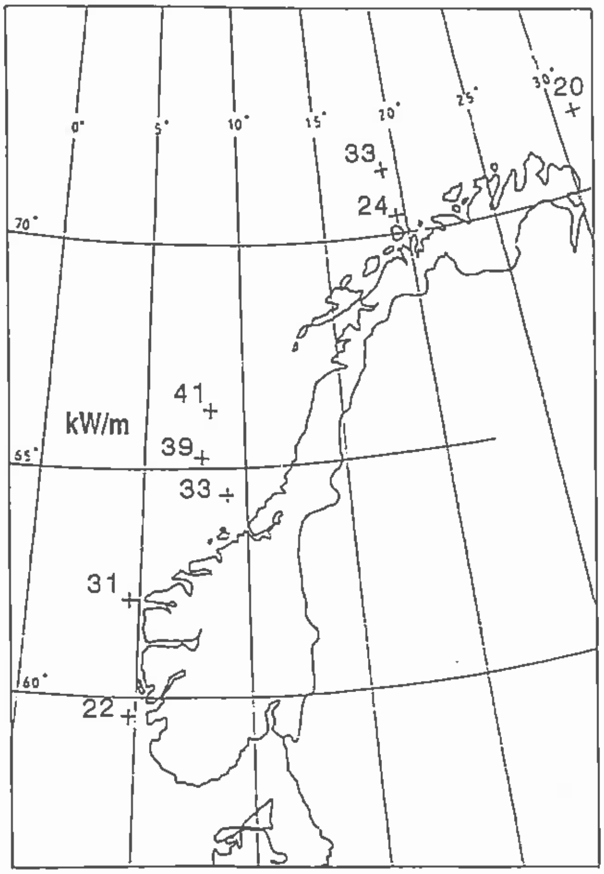

Figure 1. Average wave power transport off the Norwegian coast, as indicated by numbers (in kilowatts per metre wave frontage) at eight locations (+) where waves have been measured [10].

At the Norwegian coast the waves come mostly from directions south to west. The land "shadows" of The British Isles, the Faeroe Islands, Iceland and Norway are notable in the wave data, mainly due to the swell component [10].

The wave energy available in the ocean is very variable [4]. There is a factor of two between the highest and lowest yearly mean for one particular location. The average wave power for a winter month can be five to ten times the value for a summer month. There can be a variation of a factor of ten between two successive weeks. The wave power can be five times higher than the mean value for the week in which the storm occurs. Wave power in wave groups can in some cases be up to fifty times the wave power between wave groups.

In the northern oceans of the world wave energy is most abundant in the winter season, when the energy demand peaks. At present Norway's electric energy is almost completely produced by hydroelectric plants. With respect to seasonal variation, the precipitation normally appears as snow during the winter. Thus, natural hydropower normally peaks in spring and early summer when the snow is melting. Water is stored in reservoirs to be used the following winter. If future WE plants are connected to the electric grid, these reservoirs serve the need for storage during weeks of little wave activity off the Norwegian coast. Moreover, due to the winter abundance of WE, the water reservoirs will represent a better energy reserve for possible dry years.

As the waves approach the coast and interact with the bottom topography they are refracted. The result is that waves are focused in some locations and defocused in other locations. It is desirable to analyse this effect. For this purpose the company Oceanor operates a shallow-water wave model, the so-called HISWA model, which carries out wave propagation computations on a grid and accounts for refractive propagation of short-crested waves, including wave growth and dissipation due to wind generation, bottom friction and wave breaking. This model is often run in conjunction with the more simple backward ray-tracing approach to transfer long-term offshore directional wave climate to a chosen site. More details, as well as results of a field measurement verification study, are given elsewhere [12].

By the ray-tracing method it is possible to account for large-scale variation of the water depth. In order to account for more short-scale details of the bottom topography one has to rely on some method of solving partial differential equations. Based on the so-called mild-slope equation the company NORWAVE has developed a program to compute local regions of high or low wave activity in a coastal area as large as some tens of square kilometres [13]. Energy losses due to viscous friction and due to wave reflection may be accounted for. This program may be used together with a computer program for analysis of the "Tapchan" (see section 3.2), a program which is based on non-linear wave theory. These programs are useful for determining good locations for a wave power plant at a near-shore or on-shore site exposed to more wave energy than other sites.

Because of the shielding effect of mainland and islands the direction of propagation of swells also plays an important role for the available wave energy at near-shore or on-shore sites. This effect may be of more significance than refraction [14].

Due to the bottom topography, the wave spectrum too may be changed. In some cases a significant part of the incoming wave energy, in particular the swell component, may be transferred to higher frequencies [15].

3. WAVE FOCUSING AND TAPCHAN PLANT

3.1 Focusing wave power plant

In addition to natural focusing due to the bottom topography artificial focusing of waves may be utilised to concentrate wave energy from a certain coast length into a relatively narrow focal area. This idea led a group of physisicts at SI (the Central Institute for Industrial Research) in Oslo, working on optical and various other types of waves, into a research program to harness clean energy from ocean waves [1]. Focusing of ocean waves may be achieved by using specially shaped, submerged bodies, which reduce the waves' phase speed, analogous to the reduction of the phase speed of a light wave in a glass lens. The lens elements may be moored plates submerged to a depth of typically 15 to 30 m. Later experiments in a big outdoor wave tank confirmed the theory of focusing [16] [17]. The waves' variation in frequency, amplitude and angle of incidence can be accomodated. However, large variations require a more expensive lens system.

It was proposed to convert the focused wave energy into useful energy by means of a, shore-based, horn-shaped or tapered horizontal channel which absorbs the incoming wave and converts most of its energy into potential energy in form of elevated sea water collected in a water reservoir [5]. The waves enter the wide end of the tapered channel, and the wave height is magnified until the wave crests spill over the walls and into the water reservoir. Then the gradual narrowing of the channel causes a continuous sideways spill-off as the wave crests move along. In order to avoid reflection of wave energy, the shape of the channel must be carefully designed. The term "Tapchan" has been adopted for this type of tapered-channel WE converter. The envisaged height of the water reservoir is in the range 3 to 7 m above mean sea level for a system without focusing lenses [18]. However, the water head may be substantially higher in the case of artificial wave focusing.

A preliminary design has been performed on Norwegian focusing WE plants of power capacity 200 MW [5]: In one case the main lens was to be placed 10 km from shore and a smaller correcting lens closer to the shore. The purpose of the correcting lens was to reduce the width of the focal area to about 200 m, in order to use just one tapered channel to convert the focused wave energy to potential energy in a water reservoir. In another case a simpler lens was proposed, consisting of 70 lens elements distributed on a 7 to 10 km long line parallel to the shore, resulting in a focal area of width approximately 750 m. Then five parallel tapered channels were required for conversion of the wave energy. For both versions of the plant a head of 12 m and a maximum water flow of 2000 m^3/s through the turbine were envisaged.

3.2 Tapchan demonstration plant

Funding has not been available for construction of a full-scale submerged wave-focusing lens. However, sufficient funding was available for the company Norwave, which was founded in 1982, to construct one Tapchan demonstration unit in 1985, at Toftestallen (60° 28' N, 4° 55' E) which is exposed to deep-water waves coming from south west to west (235°-275°). The water reservoir provides a head of approximately 3 m for a water turbine of the Kaplan type, which runs an electric generator connected to the Norwegian power grid. The capacity of the machinery is 0.35 MW, and the area of the water reservoir is approx. 8500 m^2. The total length of the channel, including the wide wave-collecting part is approximately 170 m. The wide part is shaped simply by rock blasting. See figure 2. Half of the total length, the narrow, energy-converting, part of the tapered channel, is made in concrete. See figure 3. The vertical concrete walls

Figure 2. Wave increasing in amplitude as it propagates in the rock-blasted wave collector before entering the narrower energy-converting channel.

are 10 m high, of which 3 m is above the mean water level [6]. The mean tidal range is 0.9 m. Some 42 to 43 percent of the wave energy hitting the collector entrance, of width 55 m, is converted to electric energy [13]. Note that it pays to loose somewhat on the conversion efficiency rather than to invest in more concrete walls in the rock-blasted wave collector, in order to reduce viscous friction losses.

Based on non-linear wave theory and numerical computation, recent theoretical developments on the Tapchan converter indicate that it is possible to reduce the channel length considerably without significant reduction of the efficiency [13]. In order to demonstrate this experimentally, work has been started on reconstructing the Tapchan plant at Toftestallen. The reconstruction is planned to be completed during 1993. After completion the plant will have local ownership, and it will be run by the local electric utility [19].

Figure 3. Wave crest spilling over the concrete wall of the tapered channel and into the water reservoir.

4. POINT ABSORBERS AND PHASE CONTROL

4.1. Early theoretical achievements

With a background in and an experience on electromagnetic waves and acoustical waves, we considered a WE converter as analogous to a microphone or a receiving antenna, and we pointed to the advantages of designing WE converter units of small geometrical extension. The term "point absorber" was introduced for a device whose horizontal extension is small compared to the wavelength [2]. From our study [20] and independent simultaneous studies by others [21] [22] [23], it is known that the maximum power that can be captured by an axisymmetric heaving buoy is equal to the incident wave power transport associated with a wave front of width one wavelength divided by 2π. Subsequently, we made early contributions [24] [25] to the theory of an array of point absorbers. Experiments confirmed that 50 percent of the incident wave energy can be absorbed under optimum conditions, and 100 percent if a reflector is placed behind the row of point absorbers [26].

To obtain optimum conditions for maximum energy capture the absorbing system has to oscillate with a certain phase relative to the incident wave. For a single absorber this is achieved with a resonant oscillating system, which has a natural oscillating period equal to the wave period. However, since the wave period is a varying quantity and since real sea waves are not sinusoidal, a simple oscillating system with one natural period cannot, in general, accomodate the optimum condition. For this reason it was proposed by Budal [20] [27], and independently by Salter [28], to use a control system to achieve the optimum oscillation condition.

Above we considered the theoretical maximum captured energy relative to the incident wave energy transport. Another theoretical upper limit, derived for a heaving point absorber [27] relates the maximum captured energy to the physical size of the device. It can be shown that the ratio of the power output P to the volume displacement change V (heave stroke multiplied by water plane area) is less than

$$(P/V)_{\max} = (\pi/4)\rho g H/T$$

where ρ is the mass density of the sea water, g the acceleration due to gravity, T the wave period, and H the wave height. Thus, for typical wave parameters, $H = 2$ m and $T = 10$ s, we have $P/V < 1.6$ kW/m^3. The maximum cannot be approached unless certain conditions are satisfied. The oscillating body has to be relatively small ($V \rightarrow 0$), the phase of oscillation must be at optimum and the oscillation amplitude must be equal to the design amplitude. It follows that only a relatively small fraction of the available, free, wave energy is taken up from the ocean.

For most of the wave energy converter designs that have been assessed so far, the ratio P/V is less than the mentioned theoretical maximum by one order of magnitude or more. Instead most devices have been designed to capture a large fraction of the incident wave energy on a coast. However, this is not necessarily an economical optimum, since the wave energy in the ocean is free.

4.2 Phase control by latching

From the previous theoretical studies it became clear that it is advantageous to make the structure of a WE converter small in comparison with the wavelength. However, since a small oscillating body has a narrow resonance bandwidth, this advantage cannot be realised with the real waves of the ocean unless the oscillatory motion can be optimised by using appropriate mechanical components, measuring gauges and an electronic computer. A method to obtain approximate optimum motion by a mechanically simple method was proposed by Budal [29][30]. The idea is to latch a wave-absorbing oscillating buoy in fixed position during certain time intervals of each wave period. Phase control necessitates prediction of the real irregular wave some time into the future, at least a quarter or a half of the eigen period of the oscillating body [27] [31] [32] [33].

Various designs of optimally controlled WE converters were proposed by Budal. Most of them were based on the principle of latching. We also considered various shapes of the hull: cylindrical, conical or spherical. One particular proposal of a point absorber with hydraulic machinery for control and for power take-off was assessed to some extent in 1978 [30]. It was a cylindrical buoy, with a hemispherical base, 6 m in diameter. It had a hydraulic cylinder-and-piston with a vertical stroke length of 8.5 m. By means of a pretensioned cable, the piston was connected to an anchor on the sea bed. Latching was achieved by properly closing a valve in a duct between the hydraulic cylinder and a gas accumulator.

Our work utilising hydraulic machinery for conversion of wave energy was discontinued in 1979, but recently we have resumed this work again.

4.3 Power buoy with pneumatic power take-off

During the years 1979 to 1983 we paid particular attention to optimally controlled power buoys with pneumatic machinery for power take-off. The buoy could oscillate up and down along a strut which was connected to an anchor through a universal joint. Phase control was achieved by means of a latching mechanism which could clamp the buoy to the strut for a desired interval of time. Two different designs were considered. Models in scale 1:10 were tested, and preliminary design studies and assessments were carried out [5] [31] [32].

The first buoy had a conically shaped hull of volume approximately 500 m^3 [31]. Wave energy was converted to pneumatic energy by means of an air pump where the cylinder was part of the heaving buoy, while the piston was at the top of the strut. The stroke length was 9 m. The pump, which was equipped with rolling seals, pumped air into a pressure chamber (0.3 MPa). An air turbine connected between this chamber and the outer atmosphere supplied power to an electric generator rated at 0.3 MVA.

The next power buoy had a spherical hull of diameter 10 m. Instead of using a piston pump, air was pumped by means of oscillating sea water which was let into the buoy through a large opening in the lower part of the hull [32]. An air turbine was connected between a high-pressure chamber and a low-pressure chamber inside the hull.

A model in scale 1:10 was tested in the sea near Trondheim. See figure 4. The power take-off differed from that one of the full-scale version. The pneumatic power was simply.

Moreover, the latching mechanism was placed on top of the hull, rather than inside. The model was tested during six periods from 1981 to 1983. It was in the sea 170 days altogether. Modifications had to be made, in particular on the guiding rollers, the latching mechanism and the measuring equipment. The system functioned satisfactorily during the two final test periods. Between these two periods the opening in the bottom of the hull was modified in order to reduce viscous losses at the entrance [33]. Thereby the buoy shape is less spherical than originally [32]. See figure 5. Due to the viscous losses a non-linear saturation in the input power to the buoy at about 50 W and 150 W were observed before and after modification of the hull, respectively. The corresponding full-scale figures are approximately 0.15 MW and 0.5 MW. In cases with less energetic wave states, the measured input power agreed reasonably well with theoretical expectations.

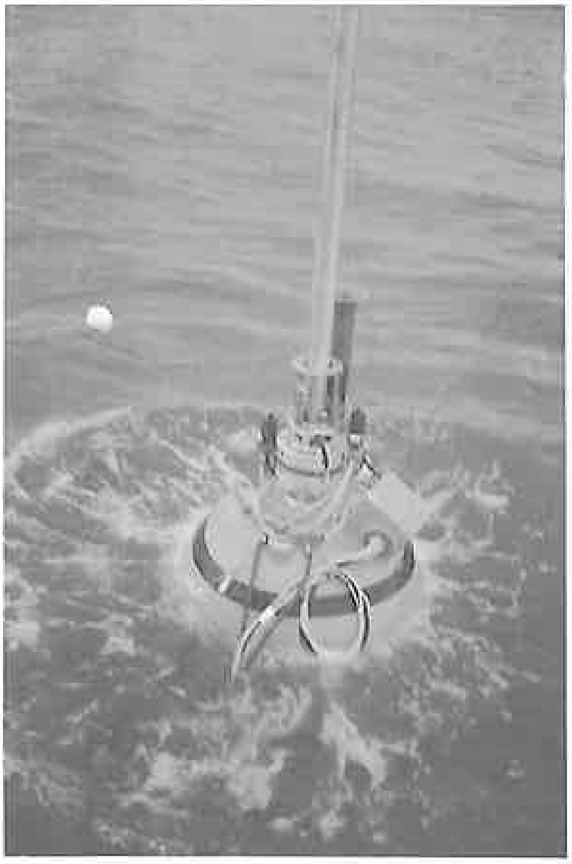

Figure 4. Model of phase-controlled wave power buoy under sea test. Here the buoy is latched in a low position.

Energy and labour are required to make any product. The energy invested in 1 ton of steel is approximately 11 MWh. It was estimated that our above-mentioned wave-power buoy would have to operate for one to two years before it had recovered the energy associated with the steel and the other materials invested in it. This energy recovery time is much shorter than for other assessed wave energy converters. However, the labour invested in our wave power buoy would have to be relatively large. Since the phase-controlled power buoy contains some critical moving parts, it is also believed that relatively much labour is required for operation and maintenance, compared to the other assessed wave energy converters. It was judged that substantial development and testing of the critical mechanical components have to be carried out before reliability and lifetime reach a level required for a power plant. This development work was, unfortunately, discontinued in 1983, when governmental

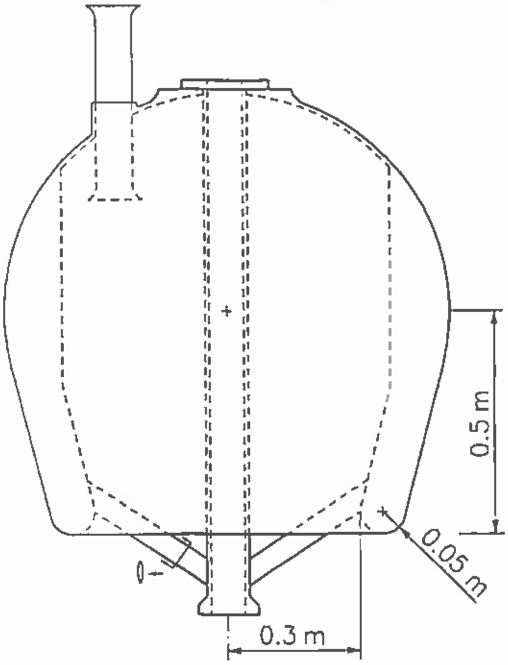

Figure 5. Spherical hull for wave power buoy model after modification [33].

funding of this wave energy project was stopped. The 50 percent private funding required for the construction of full-scale units in 1985 at Toftestallen was not available for a full-scale wave-power buoy.

5. OSCILLATING WATER COLUMNS

5.1 The Kvaerner multiresonant OWC

The first WE converter unit considered by the company KVÆRNER BRUG, Oslo, was an offshore axisymmetric buoy, optimally operated by using high-pressure hydraulic machinery [34]. Around 1980 the company decided to develop a non-axisymmetric converter of the oscillating-water-column (OWC) type.

A particular feature of Kvaerner's OWC is the pair of walls protruding from the sides of the mouth of the OWC [35]. This has the advantage that in addition to the usual OWC resonance a "harbour" resonance (associated with the short "canal" between the OWC mouth and the open sea) may be utilised to broaden the bandwidth and, hence, to improve the performance of the converter. A considerable theoretical and experimental program was carried out [36] [37]. One of the results is that the optimum length of the "canal" is of the order of one quarter of the shortest wave-length for which the converter is designed.

A preliminary design study of a wave power plant of capacity 200 MW has been made [5]. It consisted of 25 units, 8 MW each, covering a coastal length of 4 km, with a distance of 160 m between adjacent units. Each unit was an approximately 60 m tall concrete structure mounted on the sea floor at approximately 30 m water depth. The oscillating water column was 25 m wide and the internal heaving water surface had an area of approximately 560 m^2. The length of the protruding parallel walls was about 20 m. For the power take-off machinery a rectifying air turbine of the Wells type and a synchronous electric generator were envisaged.

5.2 The Kvaerner demonstration plant

Subsequent assessments indicated smaller units rated at 0.5 MW to be more economical. Such a smaller unit, land-based on a steep rocky shore was constructed during 1984 and 1985 at Toftestallen (less than 100 m north of the wave collector of the Tapchan plant). Water depths of 70 m is found less than 100 m from the construction site. The lower part of the structure (up to 3.5 m above mean sea level) was built in concrete, while the upper part was built in steel. See figures 6 and 7. For financial reasons the "canal" in front of the OWC was made shorter than the optimum length, and it was shaped simply by rock blasting. The mouth of the OWC has a width of 10 m and a height of 3.5 m (ranging from level -7 m to level -3.5 m). The internal water surface of the OWC has an area of 50 m^2. Since the width is much smaller than wavelengths of interest, the OWC prototype may be classified as a point absorber.

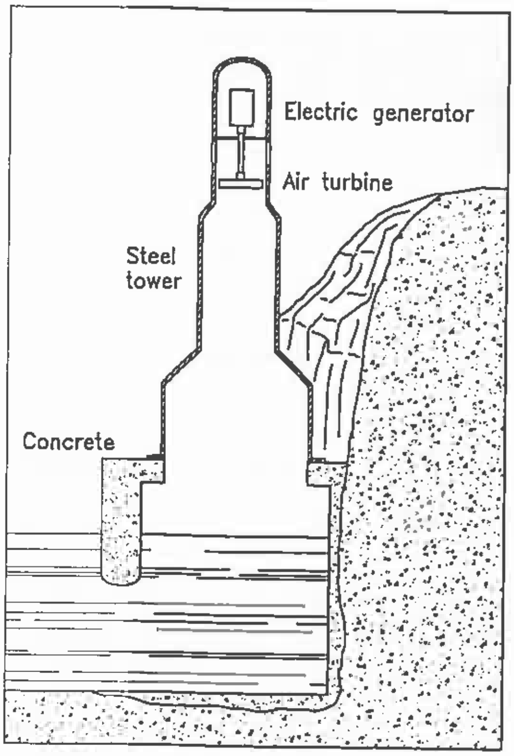

Figure 6. Oscillating-water-structure in concrete with air chamber in a steel tower, in whose upper part the air turbine and the electric generator are mounted.

After two years of testing the prototype it was reported that the basic principles developed theoretically and through laboratory testing were tenable [6]. In a heavy storm during the last week of 1988 the steel part of the plant was swept down, while the concrete part remains. The company Kværner Brug decided to rebuild the upper part in concrete, and with horizontal axis for the machinery mounted on the rock, as opposed to vertical axis in the original device (fig. 6) [38]. It was also planned to build a wave-power plant in Tonga in the South Pacific. However, in 1990, when Kværner Brug had been fused into the company Kværner Eureka, it was decided to shelve Kvaerner's involvement in wave power [39].

Figure 7. The Kvaerner OWC wave power plant constructed in a steep shore cliff at Toftestallen.

5.3 Twin OWC

With less external funding available for WE research, we have during recent years at NTH, as one of several projects, been applying the principle of phase-control to improve the OWC type of WE converter. Suppose that in an OWC structure, such as the one constructed by Kværner Brug at Toftestallen, a vertical separating wall has been erected. See figure 8. The two adjacent OWCs may be controlled for maximum power conversion by opening and closing the two air valves V1 and V2 (fig. 8) at optimum instants of every wave period. Valve V1 lets air out to the outer atmosphere, while valve V2 lets air in. Thus the valves also serve to rectify the air flow through the turbine, which means that a conventional air turbine of relatively high efficiency may be used.

We have made simulation studies [40] and model experiments [41] [42] on such a twin OWC system. In the following we shall compare such a system with a corresponding single OWC system having a self-rectifying turbine between the air chamber and the ambient atmosphere. Let us choose a geometry as for the Kvaerner demonstration OWC,

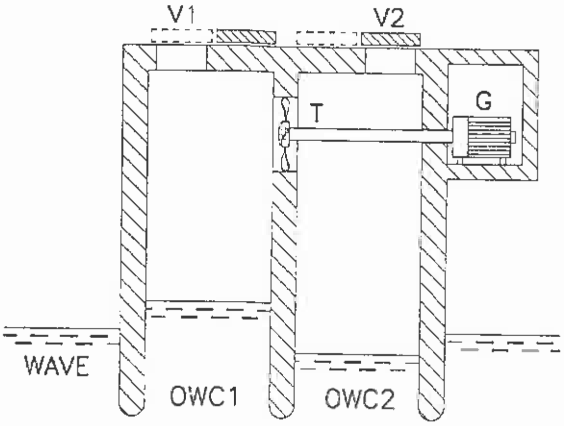

Figure 8. Schematical drawing of a twin-OWC wave energy converter. The two air chambers above the two OWCs communicate with the ambient atmosphere through the operable air valves V1 and V2 (shown in open and closed position, respectively). An air turbine T between the two chambers runs an electrical generator G.

except that the mouth area is increased from 35 m^2 to 50 m^2 (10 m width between levels -8.5 m and -3.5 m). At resonance (7 s period) and at optimum loading, the twin system cannot absorb more wave energy than the single system. At longer periods, however, the twin system is the better. For instance, experiments on a model (in scale 1:10) in regular waves have shown that at periods 9.5 s and 11 s the twin OWC system can convert 60 to 100 percent more wave energy than the single OWC system. This will more than compensate for the estimated 10 to 15 percent additional construction cost due to the separating wall and the two air valves of the twin OWC converter. A further advantage with the twin OWC system is that the optimum turbine admittance is smaller (that is, the pneumatic power is converted by the turbine at a relatively higher pressure drop and lower air flow). This means a turbine of smaller physical size.

We plan to perform additional model experiments in irregular waves. For this purpose computer software is being developed in order to predict waves and oscillations some seconds into the future, and in order to determine the optimum times of operating the air valves.

As yet there is no definite plan of constructing a full-scale demonstration unit of the twin OWC system.

6. MISCELLANEOUS

For completeness we shall mention also some other WE-related projects which have been pursued in Norway.

Since 1980 investigations have been made on the use of wave energy for propulsion of boats by means of oscillating foils [43] [44].

The principle of heave force compensation of a floating body connected to a submerged plate [45] have been applied in experiments on small navigation buoys.

Theoretical investigation have been carried out on a method to absorb waves in or reflect waves from the mouth of a harbour breakwater by means of submerged oscillators [46].

Moreover the Magnus-Budal effect is being investigated [47]. The wave force on a submerged horizontal cylinder may be controlled (increased or decreased) by introducing an appropriate stationary circulation of water around the cylinder. This effect may be utilised in new types of WE converters.

7. CONCLUSION

A short review has been given here of the Norwegian research and development of wave power.

Every year since 1978 this Norwegian program has received financial support from the Ministry of Petroleum and Energy, during the last seven years through NTNF (Royal Norwegian Council for Scientific and Industrial Research) and through NAVF (Norwegian Research Council for Science and Humanity). The annual support declined drastically during the years 1981 to 1989, but there has been a slight increase during the years 1990 to 1992.

In 1991 NTNF adopted a 4-year WE program, which was, unfortunately, curtailed at the start of 1993 when the two above-mentioned research councils were taken over by one new organisation NFR (The Research Council of Norway). At the same time two ministries were merged into the new Ministry of Industry and Energy (NOE). We hope that the new research council will decide to continue wave energy research in Norway.

While NFR is sponsoring WE research, a program for introduction of new renewable energy resources, including WE, is sponsored by NVE (Norwegian Water Resources and Energy Administration). The completion of the modified Tapchan plant (see section 3.2) is part of this program.

At the present, premature, stage of technology, wave energy can be commercial only on a modest scale, for particular offshore applications, and for saving diesel fuel in island and remote coastal communities, and on a somewhat larger scale in developing countries where knowledge and skill are available in addition to cheap labour as, for instance, in China and India. In combination with diesel power plants, WE converters of the Tapchan type may soon be used commercially for energy supply for islands, for instance in Indonesia [48]. A more advanced technology is required in order to make wave energy commercial for regional or national energy in industrialised coastal countries, like Norway. The WE research is still in its infancy. Neither the above-mentioned artifical focusing nor the optimally controlled offshore point absorber has so far been tested in full scale in the sea. Practical realisation of the latter principle requires the development of new mechanical components, electronics and software. This, as well as other arguments, which have been discussed in more detail elsewhere [49], suggests that there are good prospects for developing more cost-effective WE converters, provided sufficient funding for the required research and development will be made available. Thus, there is certainly room for further improvements of WE converters. It seems possible that wave energy could provide a significant contribution to general energy supply in the next century, even in Norway, as well as in other industrialised countries.

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