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# WAVE ENERGY PROSPECTS

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## ABSTRACT

**Prospects for wave energy can be addressed by assessing its progress towards commercial development, competition from other energy sources and by comparisons with similar technological challenges. This approach presented by the author is different from the many previous assessments where the work and claims of enthusiastic device teams has been the basis of consideration. Realistic assessment of future prospects is a very important consideration when decisions are being made regarding development funding and investment in commercial wave energy projects. Any lack of confidence in the successful application of wave energy technology has major implications for researchers and development teams. After considering the current evidence the authors view is that wave energy is unlikely to make a noticeable impact on the future supply of sustainable energy. A demonstrable breakthrough is required to radically change the prospects.**

KEY WORDS: Wave energy, wave energy converters.

## INTRODUCTION

The author has been an enthusiastic supporter of wave energy since the mid-1970s and has engaged in over 20 contracts relating to the development of wave energy technology. Early work involved testing the Salter Duck on Loch Ness in the late-1970s and led to the invention of the SEA Clam in the late-1970s. The SEA Clam featured well in the 1993 UK wave energy assessment and was considered the best offshore device. Lack of funding curtailed the development work on the Clam and the device awaits the attention of the next generation of wave energy enthusiasts.

The 20 years of experience working in wave energy, together with the last 5 years as an interested observer, has given the author a unique insight into the challenges facing this fascinating technology. Taking a neutral perspective on the prospects of wave energy is not easy particularly since views expressed have to be based on both qualitative and quantitative judgements. The author wishes to declare that he has tried to base his opinions on a logical analysis of observed trends and critical factors rather than on the mass of detail available in the literature on design and experimentation. Such opinions formed in this way are bound to be provocative and generate debate.

Assessment of the prospects of wave energy is an important consideration when considering funding developmental programmes and commercial wave energy schemes in the future. In the UK assessments of wave energy programmes have indicated wave energy is likely to be an expensive resource to harness and yet there continues a belief that further work may achieve a technical and cost breakthrough. The possibility of a breakthrough is not apparent at this stage and the hope is that the technology is still immature rather than fully developed

## METHODOLOGY OF ASSESSMENT

Assessment of wave energy programmes normally involves the use of independent consultants who report on the generic aspects of wave energy and set criteria for the assessment of device concepts presented by research and development teams. The consultants interact with the device teams on the detailed aspects of their device concept and validate or question the claims of teams with respect to technical feasibility, performance and cost criteria. Strengths and weaknesses of designs are identified and the devices compared to each other. The final report of their findings is presented to the decision-making body and made available to other interested parties. What happens next depends on the content of the report and the political and financial climate.

The approach adopted in this paper is completely different. By considering overall trends and factors one can form an opinion on the viability and credibility of a technology. For instance, the prospects of a technology like wave energy can be judged to a certain extent by considering its previous history and making comparisons with similar more mature technologies. In developing this thesis it is noted that the prospect of extracting energy from sea waves was recognised some two centuries ago and the technology has been seriously studied for the last 25 years. By now one would have expected it to have become a mature technology with commercial plant operating along coastlines of countries with particular energy needs. The fact that wave energy is not yet commercial is a message in its itself and illustrates the approach adopted in this paper. Another example of this approach to assess the prospects of wave energy is to consider marine technology where coastal structures have to be substantial, and thereby expensive, to survive all sea conditions including extreme storms over their design life. Even then many coastal structures, as in the case of ships, suffer a death rate which would add significant risks to wave energy structures designed to resist wave forces.

There are, however, a number of positive general observations in support of the prospects of wave energy. One of the most obvious is that technological advances in design and materials often overcome the most intractable problems and in the case of wave energy there are many opportunities to overcome some of the design weaknesses of existing device concepts. Unfortunately, this dependence on technology advance is speculative and only adds uncertainty to future investment plans.

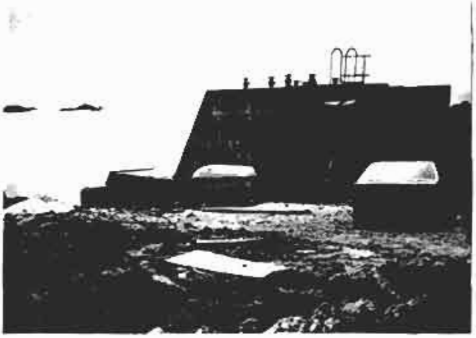

Fig. 1 OWC installation on Islay.

The parameters for assessment are many and need to be limited to those regarded as critical to the future prospects of wave energy. The prime critical factors are judged to be the four considerations; scale of resource, technical feasibility, future need and competitive cost. Prior to assessing these factors it is helpful to link the arguments presented to the work of some device teams working on both onshore and offshore device concepts.

ONSHORE DEVICES

Onshore and shoreline devices are attractive from a practical point of view. They ease the problems of access for construction, commissioning and maintenance and do not require expensive mooring. However, the energy levels onshore are significantly less than offshore and site selection is very restrictive. Examples of onshore schemes are shown in Fig. 1 and Fig. 2, both of which feature the popular oscillating water columns (OWC). The first photograph shows the shoreline OWC fully commissioned in 1991 on Islay, UK and the second photograph shows the two contrasting device designs on Toftestallen Island in Norway. The Islay OWC was built on a naturally occurring gully to reduce costs and survive storms. Its 75 kW Wells turbine is connected to the grid and all the machinery has easy land access. The unit is still providing power and data and there are plans to build similar units. The Norwegian site shows the both the cliff-mounted OWC rated at 500 kW commissioned in 1985 and the Tapered Channel (TAPCHAN) wave energy conversion system, with its low head hydro technology, commissioned in 1986. The OWC was severely damaged by storms after two years whereas the TAPCHAN which also suffered some damage has proved more successful. A more recent full-scale OWC scheme is under construction in the Azores.

Fig. 2 OWC and TAPCHAN on Toftestallen Island in Norway.

OFFSHORE DEVICES

The Energy Systems Group at Coventry University has been researching wave energy and developing wave energy devices since 1975. With the help of Sea Energy Associates Limited and the UK Department of Energy the SEA Clam device was developed and tested in 1979 followed by the reconfigured version, the circular SEA Clam, in 1984 (Bellamy,1985). A series of model tests at Loch Nests proved the device concept and full scale designs in steel and concrete were refined in 1991 (Bellamy,1992). These designs were used in an in-depth review of wave energy by the UK Department of Energy who reported its findings in December 1992 (Thorpe, 1992). Five major designs were included plus reference to three more recent concepts. The report summarised its findings by comparing the major devices regarding their state of development and the predicted electricity generating costs. It concluded that wave energy is at a relatively immature stage of development and that the shoreline OWC had the lowest generating costs followed closely by the offshore SEA Clam. This cost comparison has to be seen in the light of the potential lower resource exploitable by offshore devices as against onshore units.

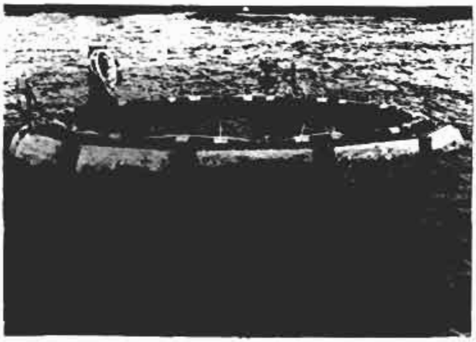

Fig. 3 Model tests of Sea Clam.

The SEA Clam, shown under test on Loch Ness in Fig. 3, is a simple device that uses the displacement of air to extract energy from sea waves. Twelve air chambers, the outer surfaces of which are formed by flexible rubber membranes, are placed around a floating ring structure shown in section in Fig. 4. Differential wave action moves the membrane in and out forcing air to be interchanged between chambers. Wells turbines placed in the manifolds between the air chambers extract power from the air flow. The rigid torus structure, 60m diameter or more, acts as a stable reference body and is moored a few kilometres off shore. Typically a 25MW scheme deployed off the west coast of Scotland, as illustrated in Fig. 5, would feature 10 SEA Clam units and produce over 50 GWh per year of electricity.

Fig. 4 Sectional design of Sea Clam

Fig. 5 Deployment of Sea Clam devices.

The SEA Clam has been designed to operate in the energetic seas off the west coast of Scotland where average power levels can reach 70 kW/m and with storm power levels of over 3000 kW/m. Predicted annual capture efficiencies for a 60m diameter SEA Clam in the characteristic sea states off South Uist, Scotland, were calculated as 33% in the wave energy review. This gives an average power per device of 600kW, an energy output of 5GWh/year and an electricity cost of 8p/kWh. The structural design is governed by the 25 year fatigue levels induced by these wave climates and the power system design relates to average sea power at a given site. Costs included capital costs of construction, installation, transmission and project management plus the operating and maintenance costs.

SCALE OF RESOURCE

The global wave energy resource exceeds the world energy demand by a factor of at least one hundred but is distributed over three-quarters of the earth's surface. This diffuse nature of the resource combined with local climate variation makes wave energy an inherent uneconomic proposition for most countries. In fact, of the various alternative energy sources available, it has been said that, after wind power, wave energy is the most variable, unpredictable and inconvenient. However, some countries, such as the UK, have relatively energetic wave climates on their west coasts averaging 50kW per metre or more and capable of providing up to 10GW average of electricity if extracted offshore. Onshore the resource is severely restricted by attenuation over the sea bed and directional factors. Coastline characteristics and environmental issues are also very restrictive when considering the location of wave plant. This leads to the conclusion that large scale wave energy has to be harnessed offshore and that onshore plant is only suitable for small scale local use.

TECHNICAL FEASIBILITY

Around 300 wave energy conversion concepts have been proposed and funded for study around the world. The variety of device designs is an illustration of man's ingenuity and persistence. Many design concepts have been recycled in different forms and have been categorised by various consultants involved in the appraisal of wave energy programmes. Principal device categories are tuned oscillators, untuned dampers and rectifiers. Different frames of reference are used to resist wave forces such as the sea bed, wave bridging structures or spines and inertial mass. Some devices are designed to float in deep water and some are fixed to the sea bed either on the shoreline or near shore. The worry from the point of view of the maturity of the technology is that there is little evidence, possibly with the exception of the OWC, of convergence of ideas or device teams willing to agree on solutions and work together. As a result there is a wide spread of innovation and effort but little focused output.

The extreme conditions which frequently prevail offshore in the western approaches of the UK and Ireland are damaging to all but the most robust of man made structures. The cost implications are significant in design, maintenance and insurance terms. Floating wave energy plant has to resist wave forces in the energy capture spectrum and be transparent in the extreme wave conditions. Fixed wave energy installations have to be capable of taking far higher wave forces than floating devices, both hydrodynamic and slamming, on their exposed surfaces. The only comparisons are the North Sea oil rigs which are designed to survive these extreme conditions at a cost which cannot be contemplated by wave energy designers.

Maintenance is often considered as a mundane activity but is certain to have a first order effect on the cost of wave energy by virtue of its duty and operating environment. Most of the feasible methods of harnessing wave energy require the deployment of large numbers of unmanned devices in an extremely hostile environment. Access to machinery to perform maintenance is severely limited and some breakdowns can be progressively destructive before repairs can be performed. Maintenance activities include servicing, overhaul and repair and are very dependent on ease of access and duration of weather windows.

Offshore floating devices have the more difficult maintenance problems than fixed onshore units. Moorings represent the most uncertain area with respect to maintenance costs and by implication have to be expensively over-designed to reduce the chances of disastrous failure. Some cost estimates for generic wave energy devices put maintenance costs in the same order as the current cost of electricity generated by fossil fuelled power stations.

## FUTURE NEED

In the long term energy needs, together with the environmental and political attractions of sustainable energy, will place a premium price on wave energy and should ensure adequate funds are made available to fully develop the technology. This has already happened for wind and small-scale hydroelectric schemes where guarantees have had a significant effect on the market place. Targets have already been set by many countries for the production of electricity from renewable sources. In the case of the UK the target of 10% of UK electricity from renewable sources by 2010 has been stated which is considered rather ambitious considering this represents a five-fold increase over present production. This represents a sizeable investment in the alternatives and should benefit UK wave energy development since no one technology can reasonably expect to expand at the rate suggested. This should give rise to some public and private funding for wave energy development teams which should improve the chances of making that all important breakthrough in the technology.

## COMPETITIVE COST

Serious study and development of renewable energy began in 1973 as a result of the first oil crisis. Wind, wave, tidal, landfill waste, geothermal and other renewable energy sources were funded by government and industry in the expectation that they would be needed to replace the declining fossil fuel resources. In the event the majority of these new energy sources could not complete with oil, gas and coal particularly in the UK. Eventually this competition from fossil fuels will cease and market forces will dictate the price levels of other energy sources including the new renewables. The future price the market will place on the renewables will be a key factor in the exploitation of one of the most challenging technologies, the development of wave energy.

The last 25 years of wave energy development have shown a number of cyclic trends of optimism and reality. Wave energy programmes supported by government policies and funding have generated innovative projects, in both universities and companies, which have been assessed by experts and peers. Examination of the assessment reports shows that new ideas often are seen as more attractive than the established device concepts that have been studied in depth. Many of these new ideas do not survive further close examination and often are not heard from again in the literature. It is still possible, although unlikely, that some innovation will lead to a technical and cost breakthrough that will have a radical effect on the prospects.

Competition from other forms of renewable energy is the long-term challenge for wave energy. Biomass and wind are the current competitors and solar promises to be cost-effective in the future. Whatever future energy scenario is examined it is difficult to see sustainable energy meeting the current and future energy demand. After the fossil fuel era, renewable energy will be pushed to meet the demands placed on it, even if market prices were many times those that currently prevail. The price ceiling might be determined by the energy costs needed to build renewable plant. Perhaps wave energy has a future if the energy input is appreciably less than the lifetime energy output.

## CONCLUSIONS

Based on the evidence to date the author's opinion is that wave energy is unlikely to make a noticeable impact on the future supply of sustainable energy. The resource is not in doubt but the cost of extraction does not compete with other sources of sustainable energy. The technical challenge of the sea environment is the key factor in the major cost centres referred to in this paper. Much will depend on the future energy demand, levels of investment and technical innovation and unless these all prove to be very favourable wave energy is only likely to be useful in small scale applications to meet local needs. The current prospects for wave energy are not good.

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