The Construction, Commissioning and Operation of the LIMPET Wave Energy Collector

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Synopsis

The paper covers the historical background of OWC development on Islay and the derivation of the LIMPET concept. The construction process is described with particular reference to the lessons learned in respect of building on a hostile shore. The Turbo generation equipment is described and the operational control philosophy explained. Information on plant performance during the first year of operation is given and operational problems discussed.

1 Introduction.

Figure 1. The LIMPET Gully

It is sad but true that in general the engineering professions do not excite the public imagination. I think that we would all agree that this state of affairs is both regrettable and unjustified. There can be little more exciting than taking what nature has to offer in the way of raw materials and fashioning them to create something either useful or pleasing to mankind. Nonetheless, unless he or she happens to be an engineer themselves, the confession of ones engineering credentials to a stranger at a party can often lead to an embarrassing silence. Fortunately this is never the case with wave energy, quite the reverse. The concept of energy from the waves somehow touches a fundamental human desire and the general public has a great thirst for knowledge and information on the subject. Since my involvement with the construction of Limpet on Islay I've found myself a popular figure at social gatherings and am in receipt of the congratulations of relative strangers who uniformly desire the success of the emerging wave energy technology. During the last two years this popular enthusiasm has been transformed into active support by the British government and in the longer term wave energy is seen as a key component of the mix of renewable energy technologies which the government is so anxious to develop. The LIMPET shoreline device pre-dates the current upsurge of interest in wave power and given that the wave energy resource increases with water depth, may ultimately prove to be on a side branch in the long term development of wave energy technology. At present however it is the largest grid connected wave energy generator in the world and has proved invaluable in providing experience in both construction and operation and as a research platform for the continuing development of wave energy systems.

The Wavegen project team take considerable pride in the fact that the successful construction and commissioning of LIMPET has been one of the main reasons why wave energy is now firing the public imagination and why wave power is now starting to get the public support which it deserves.

2 Background to LIMPET

The LIMPET (Land Installed Marine Energy Transformer) project was originated by Professor Trevor Whittaker at the Queens University of Belfast (QUB). With the support of the Dti Professor Whittaker's team had already proved the oscillating water column (OWC) principle of operation by building the 75kW Islay prototype.

Figure 2 QUB 75kW Prototype

This unit was constructed in 1991 and decommissioned in 1999 on completion of the planned research programme. The ability of the OWC to convert the energy of the gravity waves in the sea to low pressure pneumatic power was demonstrated and the pneumatic power was converted into electrical energy via a combination of Wells turbine and induction generator. Perhaps the most important outcome of the project was that it demonstrated that energy collecting structures could be built on an exposed shoreline.

In the mid 1990's the question of what came after the 75kW prototype started to be addressed. There were fundamental questions to be considered, not least of which was whether the shoreline was the region in which to focus the next stage of development. It is well accepted that, in the long term, offshore wave farms offer a much greater potential than shoreline stations. Waves lose energy through bottom friction and breaking as they migrate inshore and there is thus more energy available to an offshore device. If wave energy stations are to provide significant power to the grid then they will occupy significant areas of the sea. In general terms the closer to the shore the more competition there is for use of the sea area and right on the shoreline the competition is at its most fierce. There are also environmental reasons why it might be better to site wave energy devices far offshore; out of site and out of mind. Conversely there is a tremendous advantage in the early stages of development to have full access to the device. This will never be possible with an offshore device and the likelihood is that things will go wrong at times of storm when access is least possible. There are also cost elements such as the installation costs, moorings and grid connection charges which are disproportionately high for a prototype offshore device. There is also a great deal of information which can be gathered from a shoreline device which is of relevance to offshore work. In particular the real time testing of power take off systems, grid integration and the application of control strategies to the irregular input power. It may also be argued that whilst the potential of shoreline devices is much smaller than that for offshore systems there is still a significant commercial market for shoreline systems based on OWC technology which can be accessed much earlier than that of offshore generation . Finally there is great merit in approaching development incrementally by building sequentially on previous tests. Taking all these factors into account and noting that in the late 1990's development funding for wave energy schemes was extremely limited, QUB and Wavegen, decide that the next stage of development should be the construction of a larger shoreline OWC which it was hoped would be representative of a design which could be offered for commercial application. To that end a consortium was formed with Wavegen and QUB as the main partners and 50% funding secured for the project under the EU Joule programme. The EU project commenced formally in November 1998.

The stated objectives of the project were to :

- Construct of a shoreline OWC with a mean maximum generation capacity of 500kW.
- Connect the generator to the local electricity grid and operate the plant as a prototype power station.
- Instrument the plant to monitor environmental loads, power train performance and the quality and quantity of delivered power.
- Experiment with different control settings to optimise the matching of the plant to different sea states.
- Compare full scale performance with the predictions of mathematical and wave tank models.

The generation capacity of 500kW was chosen as being both a significant advance on the prototype device and of a capacity which would make a meaningful contribution to the supply on Islay. Whilst the island is normally fed from the mainland there is a standby diesel generation capacity of 6MW so that a small number of LIMPET sized devices would make a major impact on the island supply.

3 Basic Characteristics of LIMPET

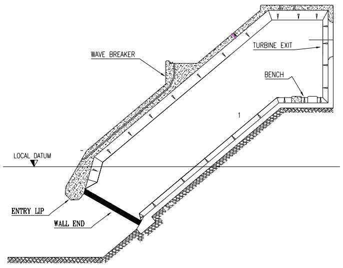

Figure 3 Section through LIMPET Collector

In a oscillating water column the wave energy collector is an open chamber inverted in the sea such that wave driven water can flow in and out of the collector via a submerged entry. By virtue of the kinetic energy of the water associated with the oscillating flow in the water column and the system "stiffness" engendered by the differential height of the water inside and outside the collector the water column will have a natural frequency of oscillation. This natural frequency is largely determined by the depth of immersion of the entry lip and relative areas of the water plane inside the collector and that at the entry. To give good coupling between the external waves and the internal column motion it is highly desirable that the column resonance should coincide with the peak energy period of the waves. This is typically around 10-11 seconds on the Atlantic shores of the British Isles.

For simplicity of construction early OWC devices including the QUB 75kW prototype were built with vertical rear walls and the resonant period of the water column was typically lower than desirable. In principle the resonance can be changed by increasing the immersion of the lip and reducing the entry area but both of these effects significantly increase hydraulic losses so that whilst the tuning is nominally improved the overall effect is counterproductive. Conversely rather than increasing the area ratio by reducing the inlet it can be increased by tilting the water column so that the water plane area increases by $1/\cos\vartheta$ where ϑ is the angle of tilt from the vertical. Tests at QUB demonstrated optimal performance at $\vartheta = 50^{o}$. There are other considerations in the design of the collector. Tilting not only affects tuning but also eases the passage of water into the column. Whilst this beneficially reduces hydraulic losses at times of normal generation it also brings the danger that at times of storm a bulk flow of water can completely fill the water column resulting in internal wave slam at the top of the structure. Model testing at Wavegen has previously shown that the sudden arrestation of a mass of fast moving water which trapped inside the collector can give rise to very large but unpredictable structural forces. The decision was made that this situation should be designed out by increasing the length of the water column in model tests until storm waves never caused water impact on the inside of the rear collector wall.

Model testing also demonstrated that there was a significant performance benefit from a dog leg at the submerged entry lip of the collector. Whilst the dog leg does not seem to impede the inflow of water it does slow the outflow. Without the dog leg the water column emptied very rapidly creating a highly spiked distribution of the outward flow during a wave cycle. By impeding the out flow the distribution is much improved with major benefits to the power conversion system.

The sloping of the collector not only eases water flow inside the collector but also makes wave overtopping from wave flowing up the outside the device much more likely. A wave breaker with a short vertical face was built at mid slope to limit overspill.

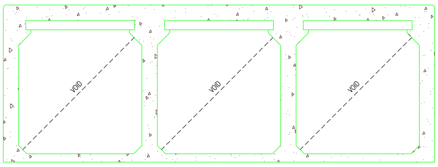

Figure 4. Transverse Section of LIMPET Collector

Based on model tests a collector width of 20m is required to achieve the 500kW rating. In respect of the design loads this span is too wide to accommodate in a single span. Furthermore a single chambered collector of 20m width would be subject to the affects of internal transverse waves which would be a major source of lost power. The collector chamber was thus split into three equal 6m square sections as shown in figure 4. The introduction of the dividing walls leads to construction problems in tying the walls back to the sloped rock surface. These problems were avoided by casting a rear wall against the excavated rock so that all the pressure loads within the chamber were contained within the structure.

Large holes were left in the dividing walls at the upper platform level so that the air from the three water columns could be combined to feed a single turbo-generation system connected on the centreline of the device. The facility for blanking these connecting holes was also designed into the plant to allow researchers to investigate the effects of changing effective column volume and damping. A second turbine outlet was also included in the design to give the option of fitting and testing alternative power take off systems.

4 Civil Engineering Construction

Figure 5. LIMPET Site

The LIMPET site is at Claddach Farm on the Rhinns of Islay. It is approximately 400m to the north of the site of the 75kW prototype but whilst the first device was built in a relatively sheltered natural gully, LIMPET sits towards the open sea and is subject to the full force of the Atlantic wave climate. The choice of such an exposed site was quite deliberate in that it is felt important to demonstrate a widely applicable construction technique rather than to develop a generation system which is highly dependent upon natural features.

The main problem in constructing a device on an exposed rock shoreline is the danger of wave inundation. A site which is benign at one time can be unworkable a few hours later. This creates major difficulties in the organisation of construction activities and in the protection of temporary works.

A number of collector designs and constructional techniques were considered in conjunction with potential contractors. Included in these were the concept of making the collector at a remote location, towing to site, winching in to position and then fixing the unit to the rock face. A variant of this was to establish a site on the cliff top, construct the collector and the slide it over the cliff edge and down a prepared rock face into position. With both of these ideas the fixing to the cliff was problematic and the collector was considered to be extremely vulnerable during the installation. These ideas were however meritorious. The method finally selected, at the strong recommendation of the preferred contractor, was as shown in figure 8.

Figure 7 Waves overtopping site

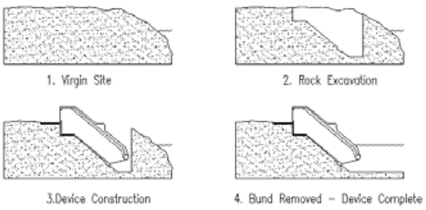

Figure 8 LIMPET Construction Sequence

A hole was excavated behind the cliff edge leaving a bund wall formed from the original rock as protection against waves.

Figure 9. Site Part Excavated

On completion of the excavation the construction commenced with the casting of the rear wall against the rock slope. This was followed by the erection of the side walls and finally the roof of structure to leave the structure complete but isolated from the sea by the wave wall

Figure 10 Structural Completion

The protection offered by the bund wall was far from ideal with significant wave overtopping preventing down hole working at various times. The degree of protection was however sufficient to limit aggregate lost time to 25% during the summer months when the construction activity had been planned. In general terms the construction team was able to use 10 day weather forecasts to predict weather down time and could plan accordingly.

The final stage of the civil engineering was to drill and blast the wave wall. A series of four rows of holes were drilled along the length of the wall and the rows blasted sequentially, with millisecond separation, with the row to seaward being the first to be fired. The objective of the sequential firing was to throw the blasted rock towards the sea and away from the structure. Prior to the blast the excavation had been pumped full of water with the objective of creating a differential head to apply an outward force to the final pillar of rock to be fired. The rock was overcharged in relation to a normal quarrying operation in order to ensure that the shattered rock was in small enough pieces to be removed by a long reach excavator.

Figure 11 Excavating Debris from Wave Wall

The reach of the excavator was 16m which was inadequate to reach the full area of the gully from the side. The initial rock removal was thus achieved by creating a rock pile in the gully on to which the excavator could drive and pull in rock not accessible from the sides. Once the bulk of the debris had been removed the excavator retreated to the sides and completed the removal from there. Needless to say the process was not exhaustive and the process was performed in October 2000 when the weather was already deteriorating rapidly towards winter. The contractor left site when the excavator could reach no more rock from the side of the gully without inspection of the collector entrance or the areas of the gully which could not be reached from the side. In fact there remained at least 300m^3 of rock which was removed by Wavegen in the spring of 2001 and which prior to this time had been blocking the collector entrance.

5 Discussion of Construction

Overall the civil engineering construction of LIMPET represents a major learning experience for the wave energy community. The Civil Engineering Contractor was selected on the basis of recommendations from Consultants and on his experience on similar coastal projects. He was taken on board the project at a very early stage and was instrumental in selecting the construction process adopted. Despite this there were major delays in the completion of the works. From a start in November 1998 the Contractor’s original programme called for completion by June 1999. In practice the civil engineering works were not completed until October 2000. Wavegen believe that the reasons for the overrun lay primarily with inappropriate planning and an inadequate focussing of resources.

The initial problems lay in the excavation of the site which in the early stages used the small scale equipment available on Islay. The limited reach of these machines required multiple handling of rock and hence a slow extraction rate. Furthermore because of the small size of the machines it was necessary for an excavator to sit in the excavation where it was in danger of inundation from waves overtopping the wave wall. It was not until a larger machine was brought in from the mainland in May 2000 that more rapid progress started to be made. In retrospect had the long reach excavator used for clearing the gully been employed on the original excavation the work could have been performed without the need for equipment down hole and with far less weather interruption. Under these circumstances the excavation could have been completed in the single month originally proposed by the contractor rather than in the five months actually taken. The failure to complete the excavation in 1998 meant that the construction could not start immediately on remobilising in 1999; furthermore the remobilisation was two months later than the original programme so that work did not restart until May rather than March as planned. This critical loss of time meant that construction did not commence until August by which the time the weather was already deteriorating and down hole working became increasingly difficult. In fact on completion of the back wall it was necessary to demobilise until the spring of 2000. The construction was completed in 2000 but again each part of the programme took longer than planned by the contractor. The main cause was again weather interruption and inadequate planning for such eventuality. Throughout the contract 10 day weather forecasts were available so that it was possible to predict with a reasonable degree of certainty when clear working spells without weather interruption were likely. Wavegen believe that the most efficient construction would have been achieved by using a flexible shift

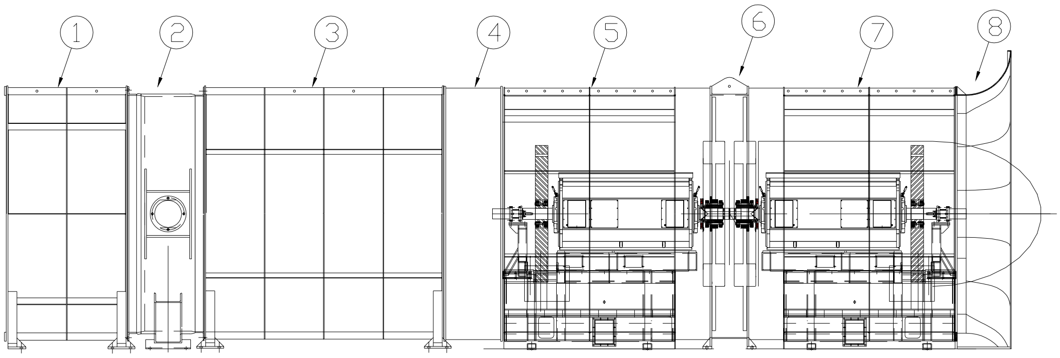

Figure 12. Turbo-generation Layout

system taking into account predicted weather, tides and daylight conditions to ensure that pours were achieved during the available working periods. The selection of plant and equipment should take both risk and benefit fully into account, for example using higher capacity plant for shorter periods. The priority of the contractor was however to seek to minimise costs by ensuring that labour was fully utilised at all times but thereby incurring inevitable rework. It is clear that we still do not have sufficient experience in building wave energy structures in exposed environments to be certain of the optimal design of collector, the optimal construction method and the best way of organising construction. We can be confident however that normal working practices applied to a coastal structure are adequate provided that the approach is focussed and flexible, and under the control of a Project Manager fully committed to the project and with experience in the shoreline environment.

6 Turbo generation system

The choice of turbo-generation equipment was based upon the need for a flexible and controllable system in order to maximise the potential of the device for providing research information whilst at the same time supplying useful power to the Islay grid. The layout adopted is shown in figure 12. The assembly is connected to the rear of the collector structure by a duct section (1). An isolation valve (2) joins the inner end of this duct to a second duct section (3) and thence to a second isolation valve (4). Two valves are fitted in respect of the safety critical nature of their function. The LIMPET is designed to supply power into the Islay grid and is reliant upon the generation torque to prevent overspeed of the turbine. In the event of a loss of grid connection a failure to remove the air supply to the turbines will result in their continuing acceleration until failure occurs through excessive centrifugal loading on the turbine blades. The valve control systems progressively close the valves as a set maximum normal operating speed is approached, and fully closes the valves in the event of grid loss or other major system failure.

The first is an electrically driven butterfly valve acting on the full duct diameter. After motoring to position the valve is held open by an electromagnetic clutch against a counterweight. In the event of a turbine overspeed or grid failure the clutch will drop out and the valve closes under the load of the counterweight.

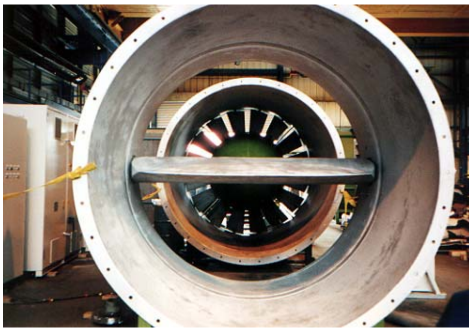

Figure 13 LIMPET Valves

The second valve is a radial vane valve acting on the turbine annulus. This valve is pneumatically operated and the design includes pneumatic accumulators. In the event of turbine overspeed or loss of grid the accumulators will discharge to close the valve in less than 1.5seconds. Both the radial vane valve and the butterfly valve are configured to permit them to be used in a modulating mode in order to reduce air supply to the turbines during periods of intense wave activity.

The flow of air to the radial vane valve and thence to the first of the turbine/generator units (5) is aided by an elliptical nosecone.

Each of the turbine/generator units comprises a frame on which sits a 250kW induction generator specially designed for the LIMPET application. The air cooled generator has a through shaft on one end of which is mounted the turbine, and on the other end of which is fitted a flywheel for energy storage. The power delivered by the OWC is inherently variable with two complete power cycles for each wave cycle. It is highly desirable that the power delivered by the system should not vary significantly in the short term. The energy stored by the inertia of the turbine and flywheel aids in this objective. A second turbine/generator unit is separated from the first by a turbine runner (6). The second unit is the opposite hand to the first so that the two turbines run in opposite directions. Developments at Queens University have shown that this contra-rotating bi-plane layout has a higher peak efficiency and a broader bandwidth than the monoplane equivalent. The 2.6m diameter of the turbine and other associated dimensions were determined by the need to match the pressure/flow characteristics of the turbine assembly to that of the OWC. This “impedance matching” is necessary to ensure optimal power capture. At the exit of the ducting is a

Figure 14 Turbine & Generator during Assembly

Figure 15. Turbo generation system - Trial Assembly

bellmouth (8) and a second elliptical nose cone.

The turbo generation system was fully assembled and tested by Wavegen before transport to site in September 2000.

Figure 16. TG System Part Assembled at Site

The mechanical reassembly proceeded without problem using local craneage.

Figure 17 Reassembled TG System

The final stage of assembly was the electrical connection for both power electronics and instrumentation with the connection between the turbo-generation equipment and the control room being made through pre-laid ducts. To provide all weather access and security for the equipment a simple building was put up around the turbine duct. The design of this building included acoustic attenuation of the turbine exit.

The LIMPET first became operational in November 2000.

Figure 18. External View of Complete Plant

7 Control System

Each of the two generators on LIMPET is driven via an inverter controlled in torque mode. The torque demand is supplied to the inverter controller by an algorithm developed by Wavegen which is incorporated into a microprocessor control unit. This overview controller fulfils three generic functions:

- The controller determines whether it is safe and desirable to operate the plant.
- It controls the starting of the machine.
- It controls the generation and operation of the plant instituting an appropriate shutdown procedure in the event of problem.

Before starting the plant the system performs a number of checks including:

- E-stop circuit closed.
- No warnings from any monitoring equipment
- Adequate energy entering the water column

If the plant start up check is passed the plant starts in the following sequence:

- Operates the vane valve to check function
- Operates the butterfly valve to check function
- Starts generator 1 and motors to a set speed. Generator 1 then enters production.
- Starts generator 2 and motors to a set speed. Generator 2 then enters production.

Once started the plant produces power under the control of the Wavegen algorithm until either a fault condition is detected or wave activity falls to a level which is inadequate to sustain generation. The control algorithm provides an independent torque reference for each of the two generators and also a position demand signal for the modulating valve (currently the pneumatic vane valve). The determination of the control signals is described with reference to figure 19.

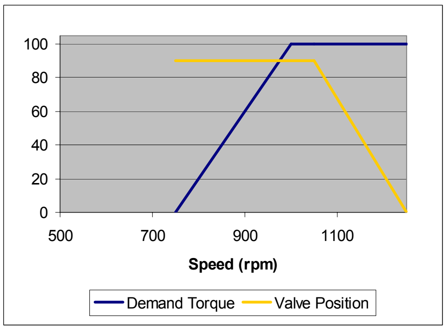

Figure 19

7.1 Generator Speed Control

There is a large rotating mass associated with each of the two turbines (1250kg.m^2 per unit) and as the energy input varies through the wave cycle power is either fed into or is drawn from the inertia in order to smooth the power supply to the grid. This is achieved by varying the torque reference signal to the inverters. The demand torque is determined thus:

- If the turbine speed falls below a set minimum the demand torque is zero. This prevents the turbine falling to a low speed from which it cannot absorb sufficient power to recover.
- When the turbine speed is above the minimum speed but below a second set speed (action speed) the demand torque varies linearly from zero to the maximum available (the maximum available being determined either from grid or generator limitations).
- When the turbine speed is above the action speed the maximum available torque is drawn.

A separate but identical algorithm controls each generator.

7.2 Valve Position Control

The function of the two in line valves (vane and butterfly) is to reduce airflow to the turbines in storm conditions and to close in an emergency. The butterfly valve is held fully open in normal operation but is fully closed in the event of a shutdown. The vane valve modulates during operation but closes in the event of a shutdown. The position of the vane valve is determined as follows:

- If the turbine is running beneath a first set speed the valve is fully open.
- Between the first and second set speeds the valve closes linearly to zero.

In addition to the overview controller there is an additional level of protection offered by hard wire controls. These provide an emergency shutdown in the event of an earth fault or a turbine overspeed.

8 Operational Performance

During a severe storm shortly after commissioning the plant in November 2000 The plant output reached the grid limit of 150kW and valve modulation occurred as planned. After this encouraging start the output of the plant appeared to fall significantly and it soon became clear that the disappointing performance was not simply attributable to low energy sea conditions. This was a possibility in that islanders have reported that in general the period 1999-2001 has seen unusually mild sea conditions. The change in plant performance was symptomatic of a blockage of the collector mouth and a diver survey was commissioned to check on this. In respect of local sea conditions the earliest that the survey could be made was mid March but the survey did show that there was an accumulation of broken rock at the collector entrance which was causing a blockage estimated at more than 75% of the entry area. An examination of the rock showed clearly that it was residue from blasting the wave wall and was unrecovered rock which had washed back into the gully during the winter. A longer reach excavator (22m) was taken to site and the residue cleared. A further diver survey confirmed that both the entry lip, the gully and the area for some way outwith the gully is now substantially clear of debris.

With the entry clear the plant performance improved significantly but still does not meet the original expectation. On the basis of the performance projected at project initiation we would have expected average generation to be approaching the 150kW grid limit during September and October. In practice the output was less than one third of this. The reasons are two fold with both relating to site topography.

8.1 Sea Floor Topography

The predicted output of the device was based upon model tests using 53 wave spectra derived by QUB as representative for the site of the 75kW prototype device. The water depths and sea bed profile modelled in the tank testing were based upon an early survey. Applying the test data to the available data on turbine efficiency an annual average output approaching 150kW was estimated. In moving to the more exposed location of LIMPET it was estimated that the incident wave power might be as much as 30% higher than at the prototype site and as such it seemed reasonable to predict a potential annual average output of over 200kW. The grid capacity at Portnahaven limits the plant output to 150kW and this has the effect of dropping the predicted annual average to 111kW. (Figure 20 Phase 1).

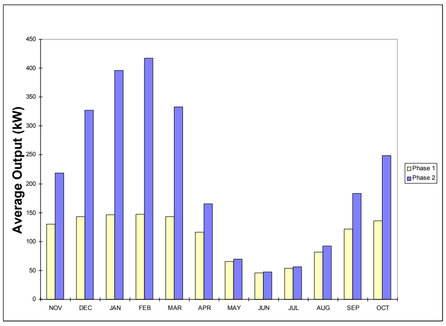

Figure 20. Predicted Annual Average

When the site was resurveyed during construction it was found that there were significant differences between the early survey and what was found on the ground. The two principal differences being :

- The water level at the cliff edge was more than 1m less than expected.
- The sea bed slope of 1:25 described on the original survey as starting at the cliff edge did not in fact start until some 60m away from the cliff.

Whilst these differences seem small the effect on energy capture as determined by model tests is dramatic with the captured power falling by nearly 50%. This is a consequence of the behaviour of waves in shallow water. As water depth reduces in relation to wave height waves increasingly "feel the bottom". Friction between the moving water particles and the sea bed causes a loss of energy in the wave and also changes the wave profile from sinusoidal to cnoidal. The reduced water depth over a relatively long distance both reduces the incident wave power and creates significant distortion to the sinusoidal waveform for which the collector was designed.

8.2 Gully Shape

The LIMPET structure sits at the end of a man made gully with straight sides and a length of approximately 17m. The productivity testing in the wave tank was performed on a model gully with a flare angle of 12.5° on each side. Research at QUB has shown that the capture performance of the OWC varies with the factor $\frac{w}{w+2*l*\sin(\theta)}$ where w is the collector width, l the gully length and θ the flare angle. Thus the capture of the parallel gully is less than 75% of the tested flare performance. As a consequence of constructional difficulties it became necessary, to allow completion of the construction within the summer season of 2000 to proceed without the flare. This was however at the expense of performance.

The combination of survey error and gully form serves to reduce the predicted output of the plant to less than 40% of the original expectation. We are still at the early stages of plant monitoring and it is not appropriate to draw full conclusions at this stage. It is likely however that on the basis of observations that even during the winter months the output will fall short of expectation and that the effects of lower water levels than expected and absence of flare will reconcile full scale performance to model predictions.

If the initial performance data is confirmed then it will be a considerable disappointment. It should however be stressed that the reduced output does not suggest that there is any fundamental problem with the principle of the OWC or the ability to develop the technology to the commercial stage but rather that there was not enough emphasis given to checking the detailed basis of design for LIMPET before the start of construction. We should also take heart that when comparing like with like the performance of the device at the full scale will replicate that indicated by model tests. This will give a major confidence boost to the designers of the next generation of shoreline devices.

9 Operational Reliability

To date the plant has proved extremely reliable and there have been no major mechanical or electrical problems. Since May 2000, save for periods allocated to research, the plant has been running under full automatic control with remote monitoring from the Wavegen offices in Inverness. During this time there have been numerous shut downs which have been caused either by a reported fault or by a decline in wave activity. Of the reported faults approximately half have been a consequence of false signals from the instruments and half due to local grid faults. In the longer term the outage due to local grid faults gives cause for concern and the lack of stiff grids at suitable sites for wave energy plant is one of the major barriers to development. We are nonetheless greatly encouraged by the relative lack of operational difficulty to date.

10 Conclusions

Overall the LIMPET project must be considered a success. We have shown that plant can be built in the hostile conditions on an exposed cliff edge and have further demonstrated that it can be operated reliably as an unmanned unit. Whilst not discussed in this paper the experience of the construction has shown us how constructional techniques can be more effectively applied to the next generation LIMPET. Whilst plant output has not yet reached the original expectation the limitations on performance are identifiable and should not form a barrier to future development. Furthermore the plant is connected to the grid and has supplied power at up to the capacity of the grid. Instrumentation has been fitted to the plant to allow long term performance monitoring with the objective of developing the turbo-generation control strategy to allow performance optimisation. It remains our belief that shoreline wave energy is worth developing and can make a significant contribution to renewable energy generation both in Britain and in other coastal states.