Potential of SMEC to Reinforce Coastal Defence Economics.

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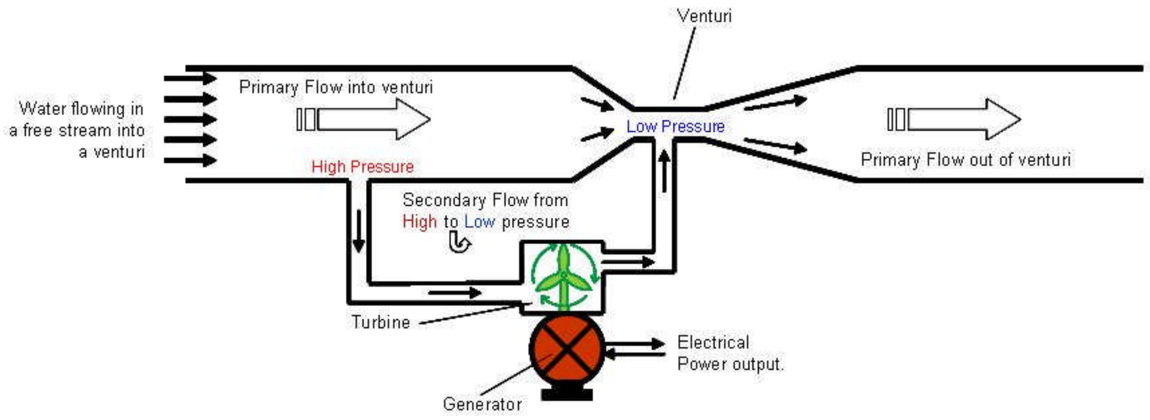
Introduction

This paper describes the potential of the Spectral Marine Energy Converter (SMEC) to create revenue from renewable electricity generation by a Coastal Defence barrier. The purpose would be to reinforce the through-life economics of the Coastal Defence barrier, thereby improving the prospects of raising construction project finance.

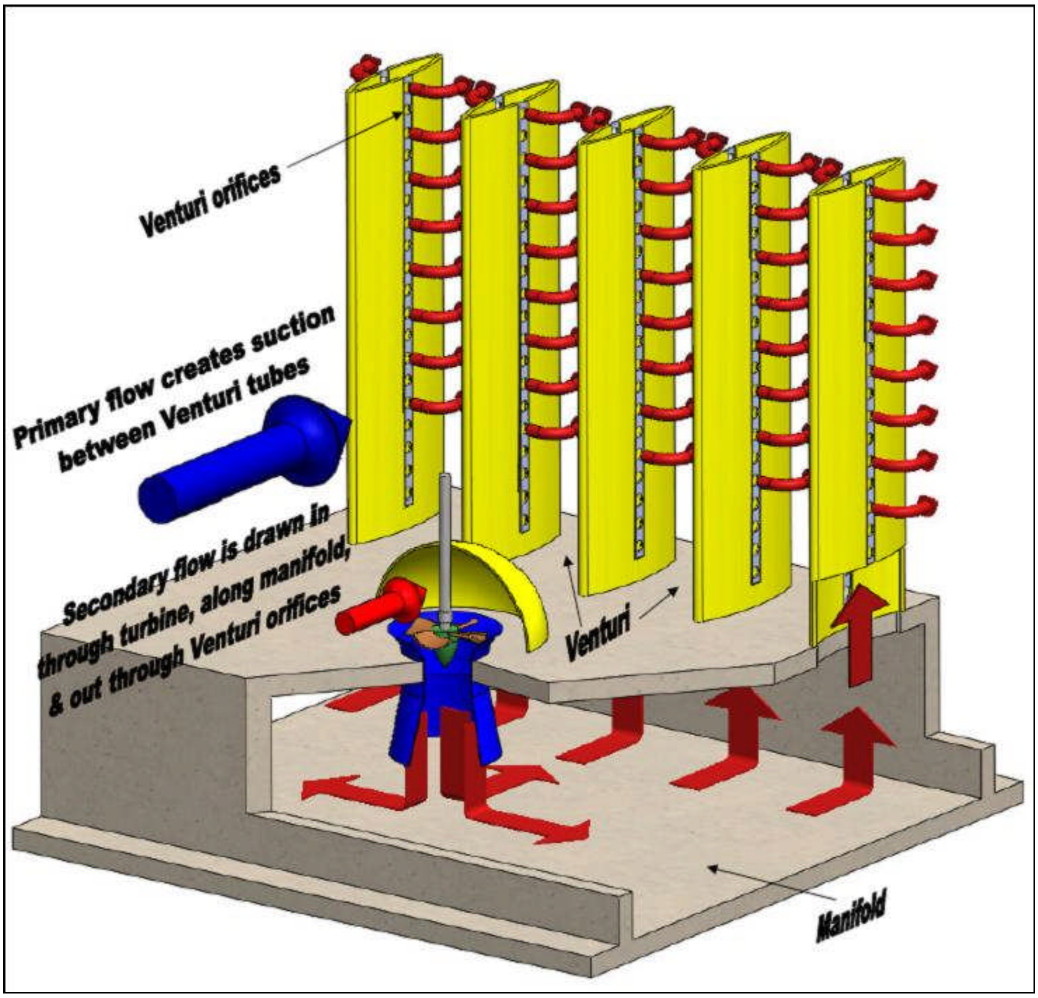
SMEC is a “Zero Head Hydro” technology comprising a porous barrier, under development initially to generate economic and environmentally acceptable renewable energy from river flows and from tidal flows in and out of estuaries. SMEC, however, can be applied to a coastal location, parallel to the shore, forming a long-shore tidal lagoon. In this configuration SMEC offers substantial coastal protection with some level of cost recovery from power generated as a by-product. The ideal site for such a SMEC is one with a high tidal range and large tidal basin.

Theoretical background

SMEC engages 100% of the tidal flow, with the majority of the stream (approx. 80%) passing through the primary path while the remainder passes through the secondary path. The primary path forms a low-pressure venturi, which draws the secondary flow through a turbine and into the low-pressure zone through a lateral orifice (Figure 1).



Circuit Diagram



(3-D sketch)

Figure 1: Basic SMEC Principles

In a practical SMEC, the venturi is formed by an array of either vertical or horizontal vanes that are profiled to operate bi-directionally. The resistance that SMEC provides to the flow causes a small upstream head rise, typically of 1m to 2 m, and it is the hydraulic energy in this head rise that is accessed by the SMEC and partially converted into electrical energy.

However, turbines have very poor efficiency at 1m to 2m head drop, which is the shortcoming of tidal fences fitted with an array of turbines in penetrations through the fence. A minimum head of around 4m to 5m is usually needed for economic turbine installations.

In a SMEC, as the tidal flow passes between the vanes, it is accelerated and a low pressure area is formed. Rows of orifices along the centreline of the vanes put the water inside the vanes in direct communication with the low pressure area in the venturi. Water inside the vanes is thereby entrained into the primary tidal flow (Figure 2). The secondary hydraulic path flows internally from the turbine intake, through the turbine to the outlet orifices in the vanes. Electro-Mechanical power is taken from the turbine.

The unique feature of SMEC is that the head drop across the turbine is amplified (on the suction side) by the venturi. The 1m to 2m head across the SMEC primary flow typically creates a 5m to 10m head drop across the turbine in the secondary flow, at which head drop the turbine works at high efficiency.

SMEC can therefore be seen as the fluid analogue of a step-up transformer that takes a large, useless, low pressure flow as input and usefully outputs a fifth of the flow at five times higher pressure.

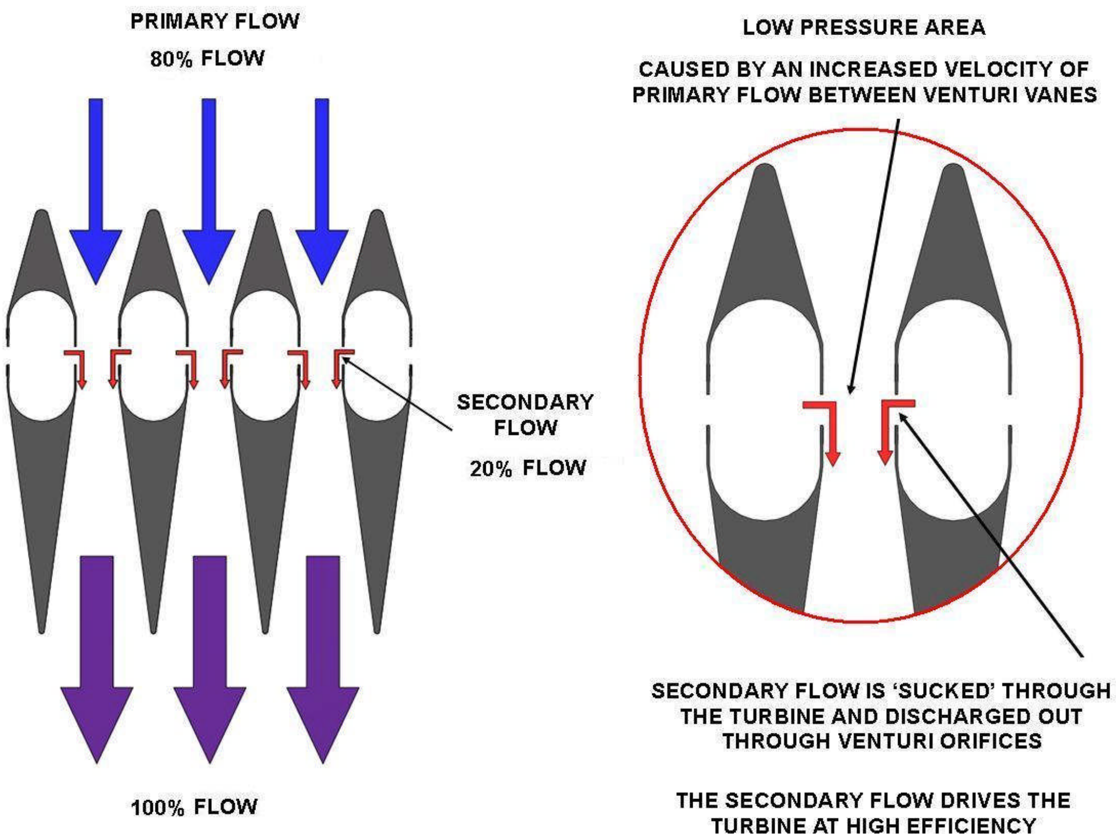


Figure 2: Flow pathways through a SMEC system

Performance of SMEC for Coastal Defence.

At the present early stage of SMEC's development, no quantified investigation of SMEC's response to wave action has been undertaken. However, given that much of the upper part of the SMEC modules outlined in this preliminary paper are a solid barrier and given that the lower "active" SMEC areas have a Blockage Ratio of around 4 to 5, it is not unreasonable to suppose that most of the incident wave energy will be dissipated and any coastal erosion inside the long-shore lagoon will cease after SMEC installation. Around 85% of the frontal area of the barrier is "active SMEC" at the 10km offset, slightly more at 5km and slightly less at 15km and 20km. It can be seen as a solid barrier with 15% actively generating electricity.

The intriguing possibility exists that some of this incident wave energy could be converted to electricity by the SMEC, further enhancing the economics. That is why a vertical orientation of the Venturi Vanes has been selected, given that the wave particle motion is in the vertical plane and will create water movements through the venturis, which are designed to work bi-directionally. Indeed, SMEC was originally conceived and patented for just such wave energy generation.

However, at the current early development stage, no quantification of any such wave energy conversion has been undertaken and all economic indicators quoted here are based solely on tidal flows.

Tidal lagoon construction and installation

Description

The notional tidal lagoon shown in Figure 3 is created at any one of the offsets from the beach by a series of SMEC units placed end to end. At some point end walls are assumed to be installed between the SMEC and the beach. In real life, this would be unlikely as advantage would presumably be taken of joining two consecutive headlands to create the lagoon.

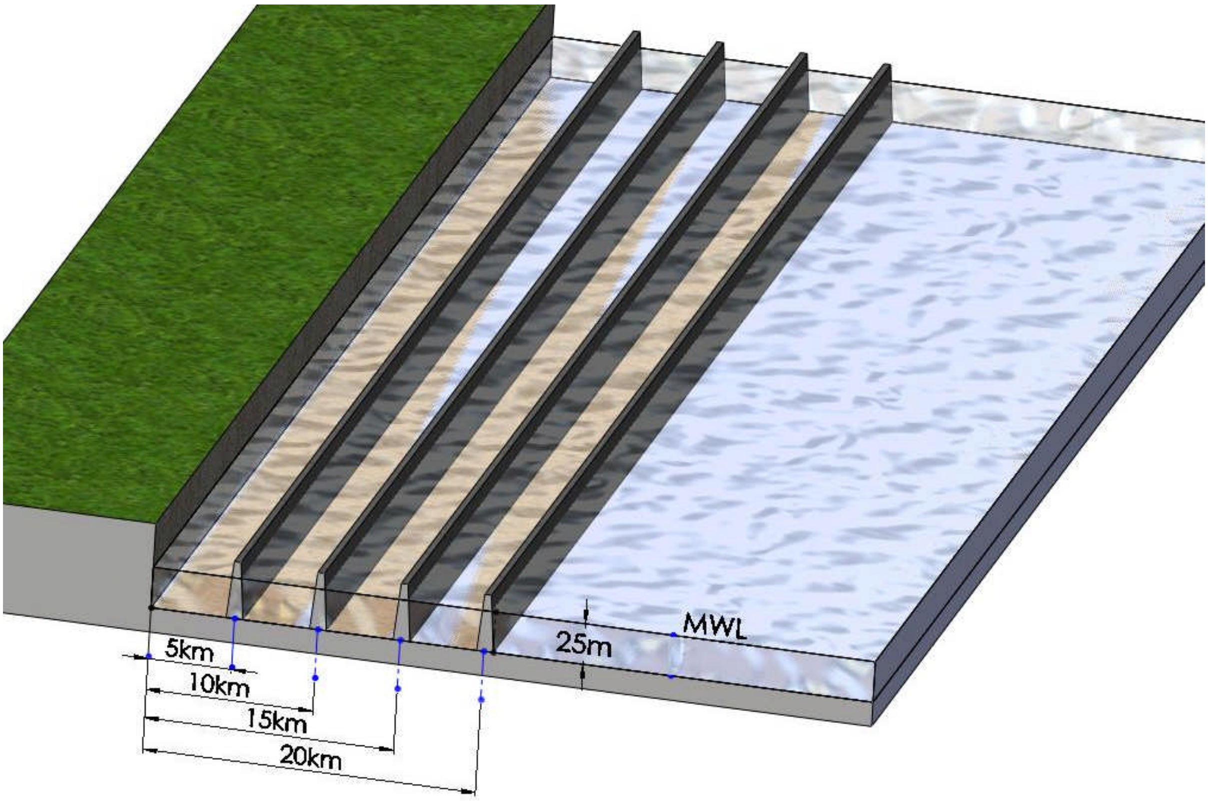


Figure 3: Idealised Coastal Defence SMEC at varying offsets from the beach

For the purposes of this initial paper, the idealised onshore lagoon created is quasi-infinite in length and all calculation are based on a typical 1km run of SMEC parallel to the beach.
Each reinforced concrete unit is a caisson extending from the seabed to about 3m above high water. Figure 4 shows the layout of a typical unit. Water flows in through an opening in the lower manifold box where the turbine is positioned. Flow travels through the turbine and longitudinally along the manifold where it is drawn, from the manifold, upwards into the series of venturi columns to the orifices running up both sides of each vane out into the venturi. The orifices are positioned below the lowest water level and a solid reinforced concrete buttress wall extends above over the tide/wave zone.

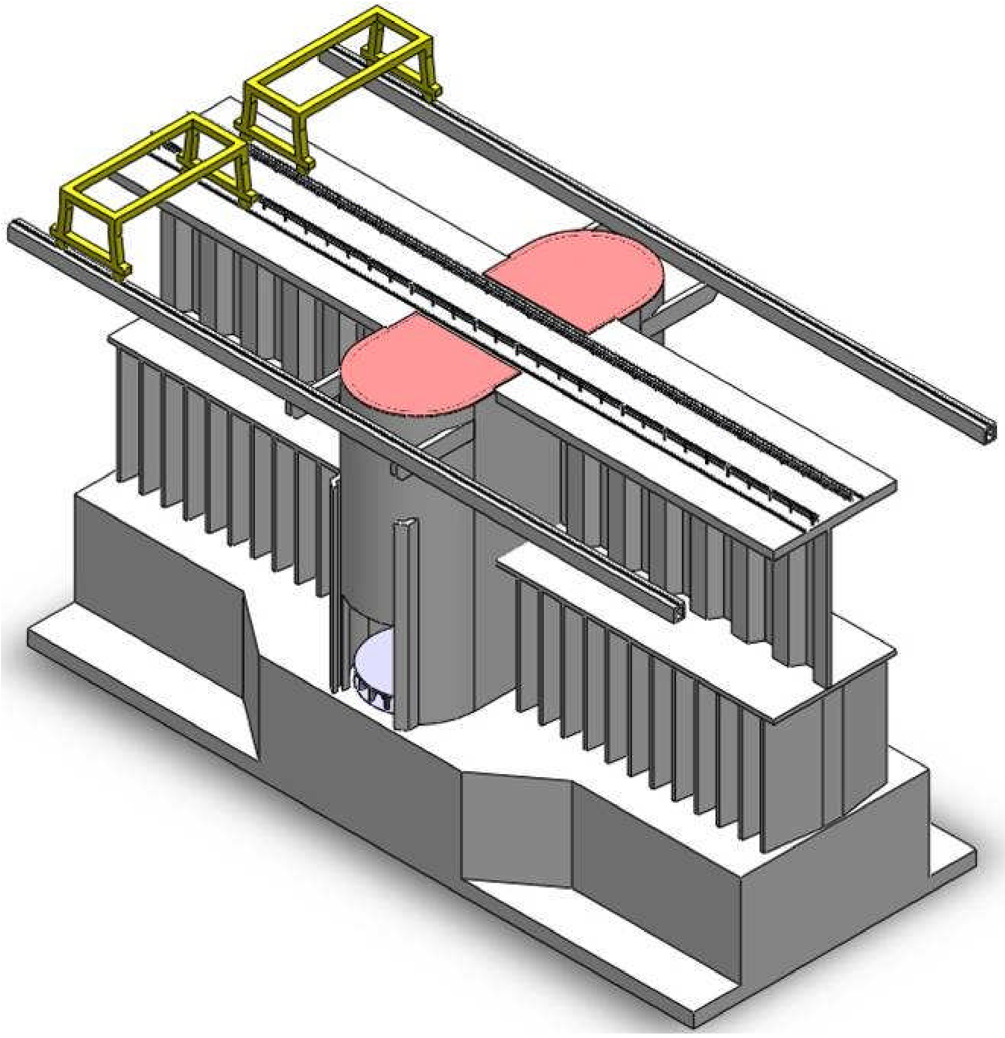


Figure 4: Typical SMEC module

Structural Design

The SMEC unit is a gravity-base reinforced concrete structure designed to have suitable safety factors against overturning and sliding under extreme environmental conditions. Particular attention is needed in reinforced concrete design and specification to ensure durability in the aggressive near-shore marine environment. The units will be towed to site from the casting facility and will be designed to be buoyant in the transit condition.

Construction

The scale of the project dictates that the units will be constructed, under factory conditions, in purpose-built casting yards. The yards will be at coastal locations so that the SMEC structures may be constructed in the dry and, after flotation, towed to site as buoyant units. This may be achieved by construction in a dry dock or by constructing the facility adjacent to a flotation basin as illustrated in Figure 5. For a large project parallel production lines may be needed to meet schedule and a notional layout of a flotation basin, is shown in Figure 6.

To achieve a high quality impervious construction, attention will be needed to concrete mix design, choice of aggregate, reinforcement spacing/cover, construction joint design and to minimising construction joints.

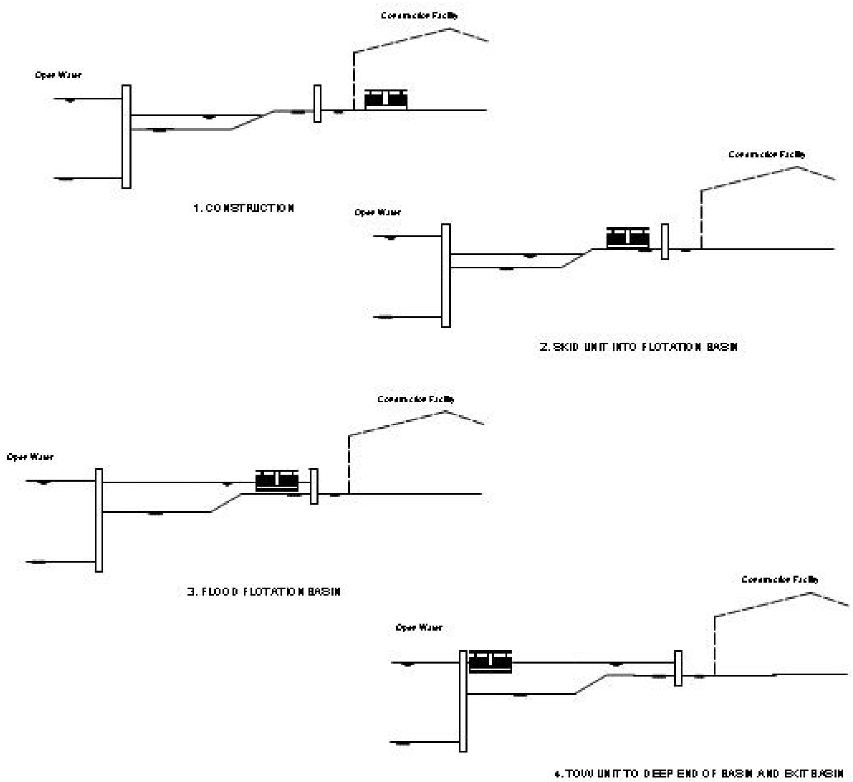


Figure 5: Construction Adjacent to Floatation Basin

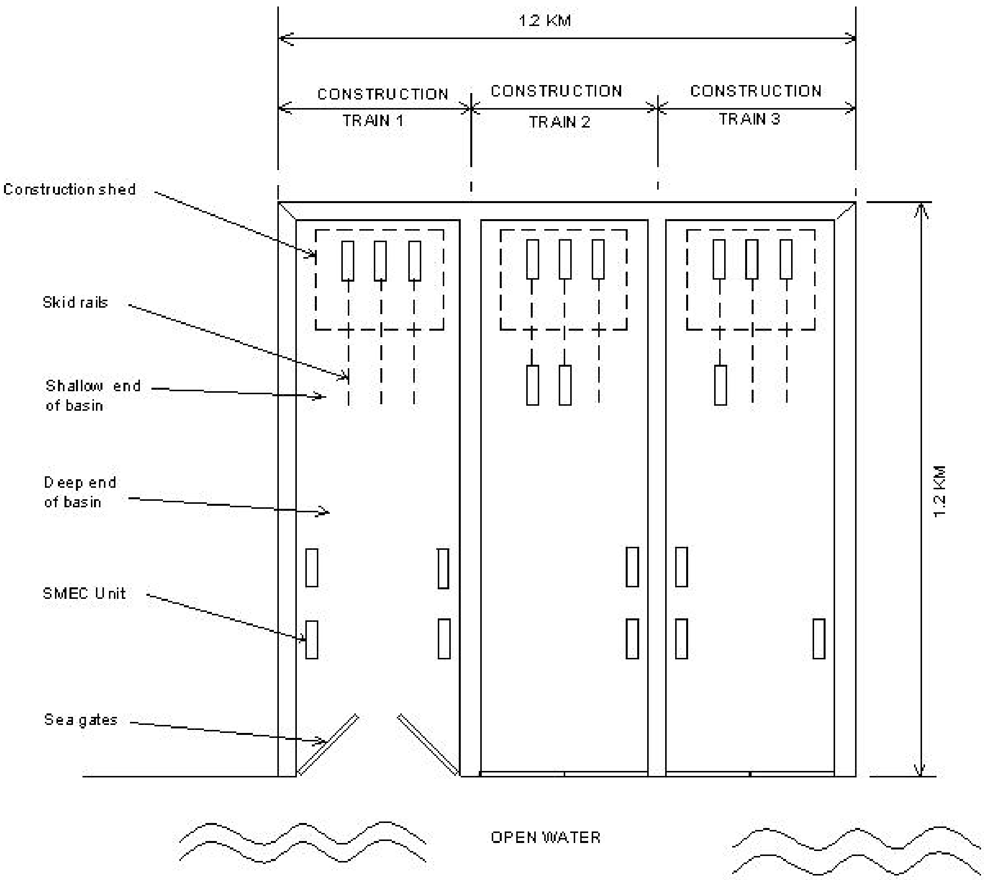


Figure 6: Construction Site Layout

Site Preparation

The SMEC units are to be positioned in a trench which is intended to bring the foundation down to a stable bearing stratum as shown in Figure 7. The trench is up to 2.5m deep and will be dredged out just before installation. A mattress of crushed rock is to be laid directly on the bottom of the trench. This is intended to bridge over any irregularities in the excavation and provide a level bearing surface for the unit.

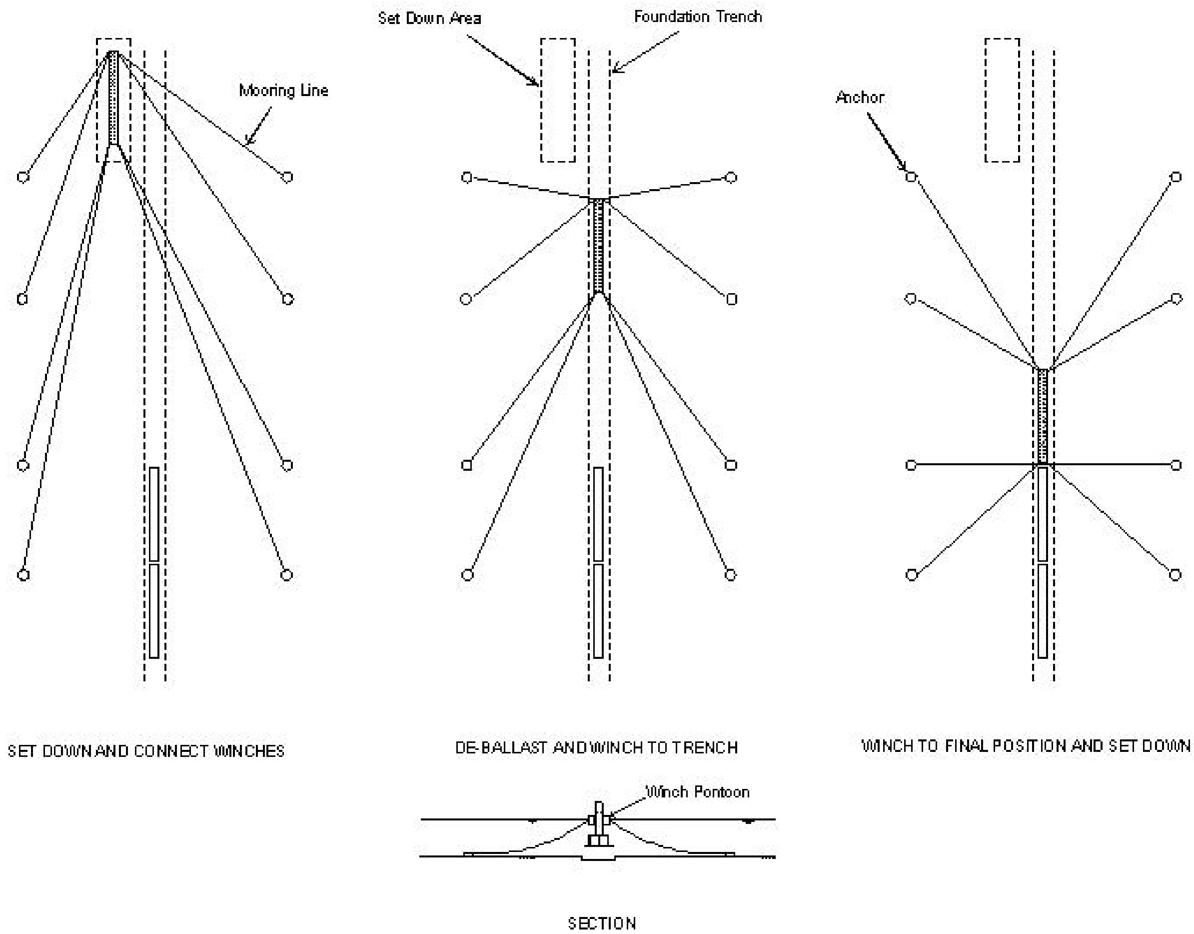


Figure 7: Installation Controlled by Winch Lines

Installation

Assuming a flotation basin is to be used, the shallow end of the basin will be pumped dry to receive the unit and the entry gate opened. After construction the SMEC module will be skidded out of the construction shop onto a platform in the shallow end of the basin. At this stage apertures will be sealed for buoyancy and, if appropriate, added-on buoyancy units will be added. Tow rigging will then be attached and the basin will be flooded. As flooding proceeds, winch wires will be attached and the unit will be winched forward to the deep end of the basin and moored in front of the sea gates. The seagates will then be opened, the tug winch wires will be attached and the mooring lines released. The unit is then towed to site by the lead tug with a trailing tug securing the rear for greater control. On arrival the unit is set down (ballasted) onto a designated area adjacent to its final location.

At the installation site, moorings will have been pre-layed and the mooring lines and barge-mounted winches will be attached. The unit will then be de-ballasted and moved to its final location using the winches. It will be set down into the pre-dredged trench using controlled

ballasting with position controlled by tension in the mooring lines. Tapered guides on the previously installed unit may be used as guides to control position. After set-down the winch rigging will be removed, add-on buoyancy will be removed (if appropriate) and the unit will be fully flooded. It is expected that currents will need to be limited to about 1m/s for this approach. This means that operations will be possible only at Neap tide periods with installation carried out as near as possible to slack water. It is expected, using this approach, that there would be two installation windows per month and that work would need to proceed on several parallel fronts to meet a realistic schedule.
An alternative installation approach, used successfully on the Eastern Scheldt storm surge barrier [Ref. 1] is based on a heavy lift vessel (HLV) offering much better positional control than the winch line approach described above. The HLV will be a new-build or converted vessel with a substantial crane capacity. With a large proportion of the weight supported on the crane (the rest by buoyancy) and with its robust dynamic positioning system, the HLV can place the SMEC unit, to the required positional accuracy, in far less benign conditions than the winch lines option. It is expected that an installation rate of one unit per week could be achieved using this approach.
After placement of the unit, the gaps between the unit and the ground and unit-to-unit will be sealed with grout and concrete. Lean mix concrete is then to be poured over the extending toes as ballast to add stability. Finally, a sloping ramp of rock fill will be installed to add further stability and achieve a smooth bottom profile.

Environmental impacts.

SMEC was conceived from the outset to offer minimal environmental impact as a performance parameter of equal significance with cost and power output. This is a consequence of its effective porosity; SMEC does not impound water or significantly distort the Tidal Signal. Figure 8 shows that the driving head caused by SMEC from which hydraulic energy is converted to electrical power is derived from a once-off phase shift in the tidal signal, which is thought to have no environmental impact, per se.

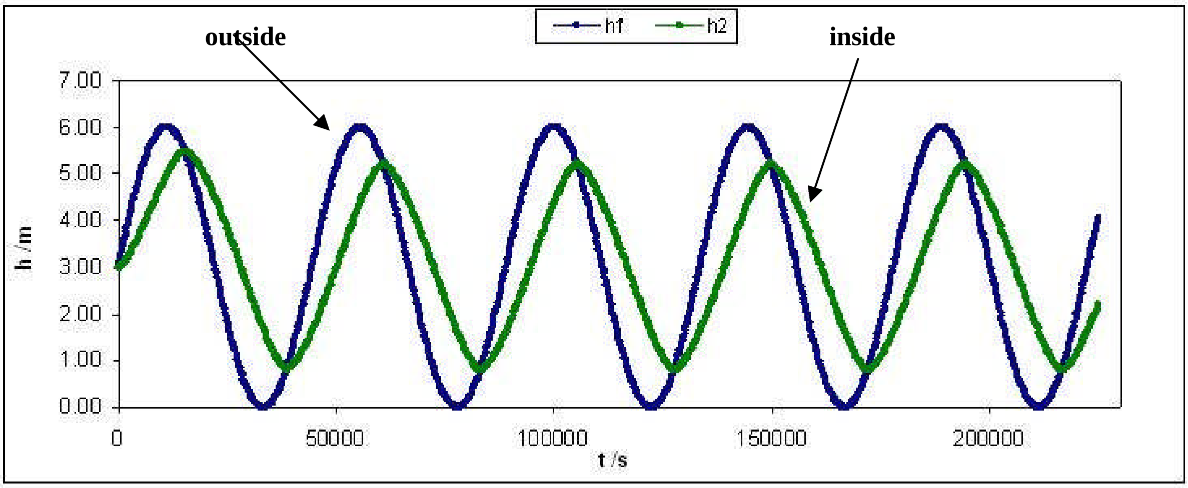


Figure 8: Effect on Basin Levels from SMEC installation
Blue (h1) is the seaward level, and green (h2) is the water level inside the lagoon.
Tidal range to seaward is 6m; range inside the lagoon is 4.5m.

All environmental impacts associated with water impoundment will therefore be minimised. That said, any device that extracts energy from a body of water must have an environmental effect but the expectation is that SMEC will have a significantly reduced environmental impact when compared, for example, to a traditional tidal barrage due to its effectively porous design. SMEC should allow a real life tidal lagoon to continue to experience most of the natural tidal range as well as the periodic exposure of estuarine mud flats that are essential feeding grounds for migratory birds. The porosity of the device should also inhibit any build up of sediment in and around the lagoon. The effectively porous design allows plenty of water in and out the coastal zone keeping the near-shore region well replenished with sea water that will prevent contaminated fresh water runoff building up to form stagnant areas

These are hypothetical claims yet to be proven during the further development of the technology. The phase-shift characteristic shown in Figure 8, however, is thought to lend credibility to these claims. A less well-bounded issue arises with defining the expected interaction of SMEC with fish, which is a major plank of current development activity at VerdErg.

What can be said is that the risks to fish from the Primary and Secondary paths are quite different. SMEC's design means, with the exception of the turbine, there are no moving parts below the waterline. With only 20% of tidal flow passing though the turbine, fish strike rates are greatly reduced, statistically, compared to any form of barrage of equal power output. This also makes screening the turbine inlets relatively simple, if that is proven to be necessary. The passage of fish in the primary path, swimming between the Venturi Vanes is more complex and still under study. The basic issue is the tolerance of fish to the low pressure transit through the venturi. This varies from species to species and also with age and pressure assimilation to the position of the fish in the water column immediately before transit. Fish with swim bladders react differently to fish without swim bladders. It also varies with Spring and Neap tides and from slack water to high tidal flow. The indications to date, however, give grounds for hope that in a SMEC as envisaged for this application, further study will succeed in demonstrating acceptably low levels of risk to fish passing through a SMEC.

Economic Case studies.

A spreadsheet-based approach has been used to characterise the impact of varying the major parameters of tidal range and SMEC offset from the beach, which controls the volume of water passing through the SMEC at each tide. Where possible, all other parameters are frozen to clarify the results. As can be seen in Figure 3, an idealised situation was taken of a straight coastline and constant 20m deep water out to 20km offshore. A quasi-infinite SMEC was placed in turn at 5km increments up to 20km. The tidal range at Springs was taken to be either 3m, 5m, 7m or 9m to bracket the tidal range found around the British coast. No attempt was made at this preliminary stage to specify locations where coastal defence is needed.

A major design study of SMEC across the Severn Estuary was undertaken by VerdErg in early 2010 for DECC, in conjunction with DEFRA, SWRDA and the Welsh Assembly Government. This was called the Severn Embryonic Technology Scheme (SETS) and VerdErg's Final Report can be accessed on the DECC website, for reference. To maximise traceability of the numerous cost data used in this short Coastal Defence paper, the same unit costs and estimating algorithms have been used as were defined by DECC to be used in SETS by all participants. The cost of power numbers quoted here are for a 5% discount figure over a 125 year design life with turbine replacement every 40 years. A plot of the results is shown in Figure 9:

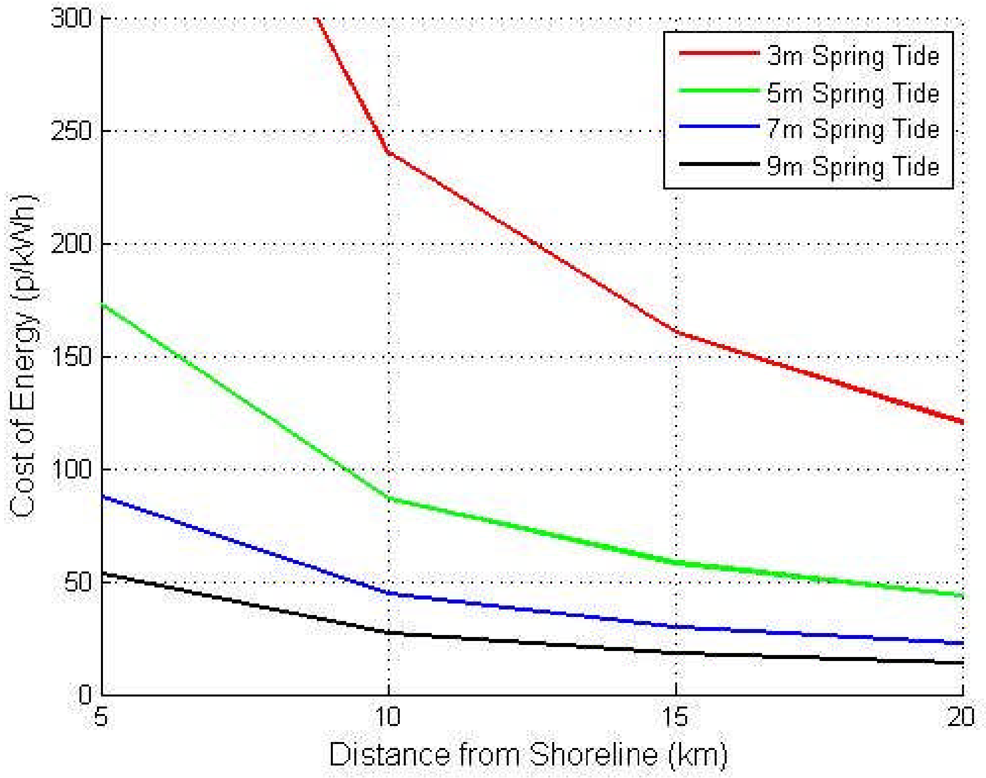


Figure 9: Cost of Energy for increasing distances from the Shoreline

Conclusions

Preliminary parametric investigation indicates that the renewable energy from a Coastal Defence SMEC can reinforce its economics significantly.
No monetary value has been assigned to the benefits gained from the installation's primary function of Coastal Defence; the renewable energy revenue stream is carrying all the costs. It is worth remembering that only around 15% of the Coastal Defence barrier is active SMEC; so if marginal economic analysis was conducted to investigate the benefit of adding SMEC to an already-funded essential Coastal Defence barrier, its economics could be transformed dramatically.

Where the tidal range is high, a SMEC placed well offshore, parallel to the coast, can output sufficient renewable energy to provide commercially attractive power output on a stand-alone basis, without monetising any benefits of the resultant coastal defence.