Recent developments in wave energy along the coast of southern Africa

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Abstract

The current status of wave energy development in southern Africa is presented by highlighting previous and more recent studies conducted on the wave power potential along the southern coast of Africa. These studies found a significant wave power resource that is evident by the interest of international developers of wave energy converters to deploy their devices along this coast. An updated version of the original Stellenbosch Wave Energy Converter, or SWEC, is presented. This shore-based device will overcome some of the difficulties of the original SWEC and may become a technology demonstrator for a full-scale SWEC.

Keywords: wave energy development, wave power resource, wave energy conversion

Nomenclature

H	=	wave height
T	=	wave period
P	=	wave power

Subscripts

s	=	significant
p	=	peak

1 Introduction

The southern African coastline is exposed to an energetic wave power resource that, if effectively harnessed, could greatly contribute to the supply of renewable energy in southern Africa, local economic growth and the empowerment of African countries to independently generate clean electricity. An energy resource can only be successfully exploited if the resource itself is well understood, defined and harnessed. The South African wave power resource was quantified by means of analyses of measured and modelled wave data in a recent study conducted at Stellenbosch University [1].

The effective conversion of the South African wave energy resource has been extensively research, at Stellenbosch University in particular, since the early seventies. Originally the Ocean Energy Research Group (OERG) investigated the different sources of ocean energy along the South African coastline and concluded that only wave energy and the Agulhas current contain sufficient power to be commercially exploited. The research effort then led to the development of novel, indigenous wave energy converter (WEC) device designed for the prevailing wave conditions off the South African coast.

There are various drivers for wave energy development in South Africa some of which include:

- An abundant wave energy resource in close proximity to populated coastal regions.
- Commitment of the South African government to generate 10 Terra Watt hours (TWh) per annum from renewable energy sources by 2013.
- Well established local coastal engineering consultancies and shipping/port facilities to support a marine renewable energy sector.
- As most of the existing generation capacity is inland, approximately 1 500 km away from the coastal areas, additional generation capacity at the coast will strengthen the national grid.

The above drivers for wave energy development and the recently introduced feed-in tariffs in South Africa have stimulated a renewed interest by local and international developers of WECs to investigate these opportunities.

2 South African wave power resource and dominant wave conditions

The south-western coast of the African continent is exposed to an energetic wave regime generated by eastwards moving, low pressure systems created in the south Indian and south Atlantic oceans. The passage of these depressions with their associated cold fronts and wind fields is the main cause of ocean wave energy reaching the south-western African coastline. A secondary source of wave energy generation on the south-eastern African coast is the presence of tropical cyclones in the western Indian Ocean [2].

By analysing wave data measured at wave recording stations distributed along the South African coast (refer to Fig. 1) the coastal zone with the greatest wave power resource can be identified and the dominant wave conditions can be determined.

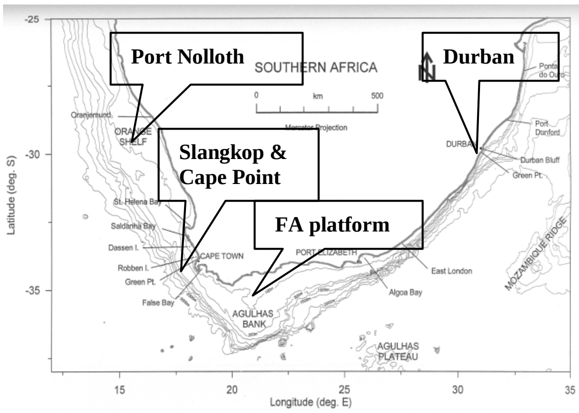

Figure 1: Distribution of wave recording stations along the South African coast [1]

Statistical parameters of significant wave height (Hs), peak period (Tp) and wave power (P, kW per meter wave crest) are presented in Table 1 which gives an indication of the expected average, 90% probability of exceedance and 5% probability of exceedance of wave power on the South African coast.

Recording station	Ave Hs (m)	1:100 year Hs (m)	Ave Tp (s)	Ave P (kW/m)	5% P	90 % P
Port Nolloth	2.1	9.2	12	26	73	7
Slangkop	2.5	11.8	12	39	110	10
Cape Point	2.5	11.8	12	39	114	9
FA platform	2.7	12	9	36	106	8
Durban	1.7	7.8	10	14	36	5

Table 1: Statistical parameters of measured wave height, wave period and wave power averaged over a year

The statistical parameters in Table 1 confirms the relatively high energy intensity of the southern African wave regime with the maximum average annual wave power found at the Slangkop and Cape Point stations of approximately 40 kW/m. From this comparison, amongst others, it can be concluded that the southwest coast has the greatest wave power resource due to its close proximity to the storm generation zone in the lower latitudes.

A detailed analysis of the spatial distribution of wave power of the southwest coastal zone was conducted in [1]. The analysis included the development of a wave model, using SWAN wave model, to simulate 10 years of hindcast National Centre of Environmental Prediction (NCEP) wave data from deep sea into the focus area and to extract statistical parameters of the wave power distribution. The mean annual average wave power distribution map of the southwest coastal zone based on 10 years of NCEP hindcast wave data presented in Fig. 2 is an example of output from the model.

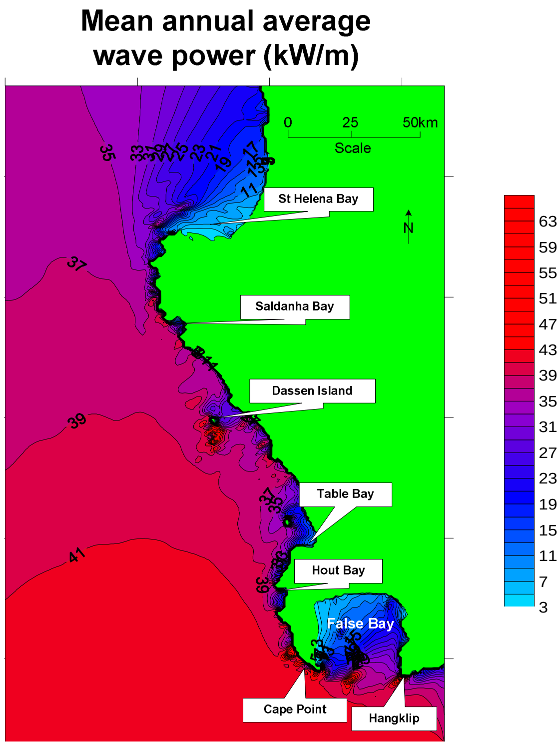

Figure 2: Mean annual average wave power distribution of the southwest coastal zone based on 10 years of NCEP hindcast wave data in kW/m crest length [1]

Some important conclusions drawn from Fig. 2 include:

- The southern Atlantic Ocean is the main source of wave power in the southwest coastal zone.
- The wave power resource is a maximum in the south and gradually decreases in a northward direction.
- The orientation of the wave power contours indicates a dominant southwest wave direction.
- Definite wave power concentration zone exist e.g. Cape Point and Dassen Island.
- The deep sea wave power resource ranges from 33 to 41 kW/m.

Similar maps were generated for the annual-, seasonal- and monthly average, -5% probability of exceedance and -90% probability of exceedance of wave power. The effective conversion of this abundant energy resource has been extensively researched over the years. A summary of research conducted on wave energy in southern Africa is presented in the following section.

3 Overview of wave energy research in southern Africa

The oil crisis in the late seventies forced governments of the world to look to alternative sources of energy. During this time, the privately funded Ocean Energy Research Group (OERG) was established at Stellenbosch University to investigate the potential for ocean energy harvesting in South Africa. An initial assessment of the available ocean energy resources indicated that South Africa has an abundant resource of wave energy and lead to the development of the Stellenbosch Wave Energy Converter (SWEC).

The SWEC consists of a pair of submerged collectors (arms) coupled in a V-formation to an air turbine and generator mounted above the water level in a tower at the apex of the V. Each collector arm consist of 12 oscillating water columns (OWC) chambers in which water level oscillations displaces air via inlet and outlet valves through to low and high pressure manifold systems which is connected to the air turbine in the tower. This is a near shore system thus reducing the transmission distance and consequent high cost of underwater transmission cabling. The SWEC is founded on the seabed which provides a fixed reference frame and eliminates the need for complex mooring configurations (refer to Fig. 3).

Two and three-dimensional physical model studies (1:50 and 1:100 scale) were conducted in the hydraulic laboratories of Stellenbosch University and Council of Industrial and Scientific Research (CSIR) to assess the conversion efficiency of the SWEC device and to optimise its design parameters such as length of collector, orientation of device and internal geometry of oscillating chambers. The structural stability and impact of the device on sediment transport processes were investigated in scale model tests.

The cost of electricity of the SWEC compared favourably to those of nuclear power and coal-fired power at the time, but a drop in oil price in the early nineties saw the project shelved [3]. With the recent renewed interest in renewable energy, driven by climate change and energy security concerns the possibility to implement this indigenous design as a cost effective way to harvest wave energy is again considered.

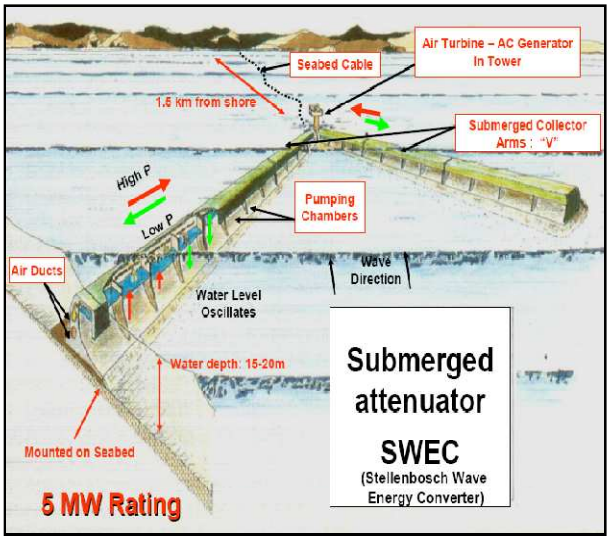

Figure 3: A full scale 5MW SWEC unit

A study was recently conducted at Stellenbosch University to design the airflow system and the unidirectional axial flow turbine of the SWEC. The study included the development of a numerical model describing the airflow induced by water level oscillations in the OWC chambers of the SWEC. Output from the numerical airflow model was validated through comparison with output from physical scale model testing. The SWEC design was optimised in terms of the orientation and size of the air ducts, inlet and outlet turbine ducting and positioning of valves for flow rectification. A technical specification was prepared for a 5 MW turbine and generator. Lastly, the selected turbine was modelled to generate power while withstanding fluctuating loads under prevailing wave conditions using CFD packages.

In order to reduce the high capital costs and the complexity of obtaining the required permission to construct a prototype an adaptation of SWEC was patented by Stellenbosch University called the ShoreSWEC. A brief description of the ShoreSWEC and its operational principle is presented in the following section.

4 Current status of wave energy projects and activities

ShoreSWEC

The ShoreSWEC (refer to #1 in Fig. 4) is an OWC WEC integrated into a caisson breakwater structure. Integrating wave energy converters in (new) coastal structures has the main advantage of sharing cost between the breakwater and the WEC in addition to the advantages over "normal" breakwaters by reducing loads and wave heights in front of the device (refer to #6 in Fig. 6), as the wave energy is absorbed and not reflected [4].

The ShoreSWEC is orientated at an oblique angle to the dominant wave direction (#10 Fig. 5) to ensure that the chambers (#38 Fig. 4 & Fig. 6) operate sequentially as each wave moves along the length of the device. The ShoreSWEC comprises of a series of OWC chambers placed in a breakwater founded on the seabed and extends above the still water level. Wave induced water level oscillations (#70 Fig. 6) force air into and out of the chamber via unidirectional valves (#40 & #42 Fig. 6) located in the roof of the chamber. The valves are connected to high and low pressure conduits (#44 & #46 Fig. 4) which run along the length of the roof of the device. The conduits form a closed circuit pump system which drives a unidirectional air-turbine (#56 Fig. 6) at the far end of the device.

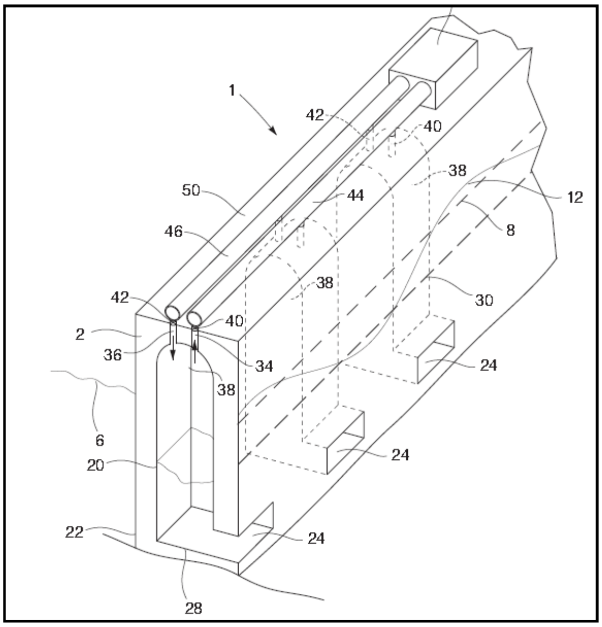

Figure 4: Part-cross sectional view of the ShoreSWEC

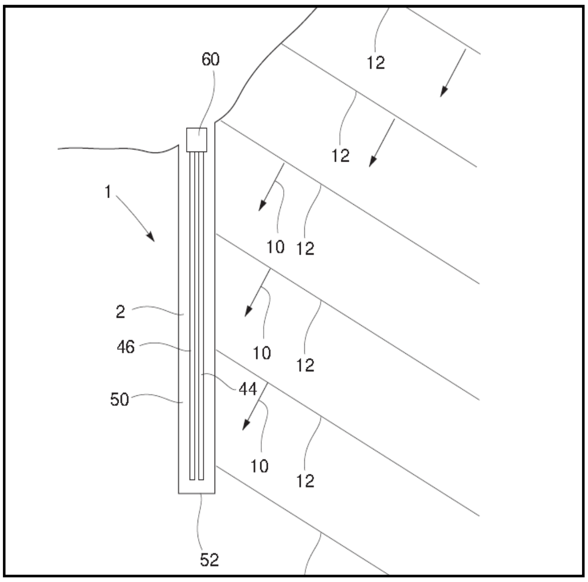

Figure 5: Top view of the ShoreSWEC orientated relative to the dominant wave direction

The power take-off (PTO) of the ShoreSWEC is located above water (#56 and #58 in Fig. 6), onshore making it easily accessible for maintenance purposes and less exposed to corrosive sea water. The ShoreSWEC can readily be incorporated into any coastal- or port development to supply power and provide sheltered waters for anchorage or coastal protection provided that the correct orientation to the prevailing wave direction can be achieved. This dual functionality will reduce the initial capital investment of the device and there is a greater likelihood of obtaining permission to deploy a prototype within an existing coastal development.

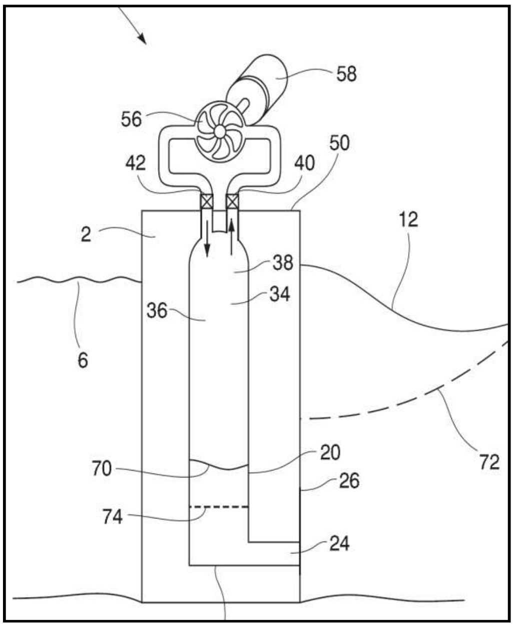

Figure 6: Cross sectional view of the ShoreSWEC and its PTO

The technical feasibility of ShoreSWEC device will be assessed by means of numerical and physical model testing at Stellenbosch University.

Ocean energy forum

The first South African workshop on ocean energy with a focus on wave and ocean current energy was held in the Western Cape on Thursday, 21 February 2008 at the Spier Conference Centre. The workshop was hosted by the Centre for Renewable and Sustainable Energy Studies (CRSES) on behalf of the South African National Energy Research Institute (SANERI) and Eskom Research and Innovation Department (ERID). Sixty delegates representing academia, the public and the private sector participated in the workshop. The main outcome from the workshop is that the South African government, the national utility and the academic community must work together to promote wave energy development in South Africa.

Other research

South Africa's national utility, Eskom, is currently employing the CSIR and the Department of Marine and Coastal Management to conduct a study to identify possible sites on the South African coast suitable for wave energy conversion. Potential sites are identified and evaluated based on but not limited to the following site selection criteria:

- The available wave energy resource based on recorded wave data (CSIR collects and manages wave data measured at various wave recording stations on behave of South Africa's National Ports Authority)
- Proximity to the transmission network and onshore grid connections as determined by a GIS-based analysis.
- Proximity to ecological sensitive coastal regions such as marine national parks.
- Proximity to active ports for manufacturing, operation and maintenance purposes.
- Proximity to shipping routes and commercial fishing activities.

The next phase of the study will include a detailed analysis of the wave energy distribution at specific locations based on numerical wave modelling of hindcast wave data. Eskom will also fund the deployment and operation of wave recording buoys at specific locations from May 2009 for a three year period.

Commercial developments

Leading international developers of WEC technology has in recent times identified the potential for wave energy development in southern Africa with various projects planned for the southwest and south coast. The Scottish based Pelamis Wave Power Ltd has identified sites on the southern Cape coast of South Africa for deployment of their Pelamis attenuator WEC device after an initial resource assessment. Finavera Renewables conducted a preliminary feasibility study for the deployment of Aquabuoy devices on the South African southwest coast in 2006. Other wave energy developments include a 15 MW wave farm to be developed on the Namibian coast by Oceanlinx, an Australian based company.

5 Conclusions

South Africa has an abundant wave energy resource available for wave energy conversion with a mean annual average deep sea wave power of approximately 42 kW/m dropping to 39 kW/m near the shore. A novel, indigenous WEC, called the SWEC, was developed at Stellenbosch University in the past to effectively convert ocean energy in the prevailing wave conditions of South Africa.

The ShoreSWEC incorporates the basic design concept of the SWEC into a breakwater structure which increases its economic feasibility due to the sharing of cost as well as less complicated licensing agreements and environmental impact assessments. Wave energy extraction furthermore reduces wave loading on the breakwater and by deploying a prototype in an existing coastal development the likelihood of obtaining permission is increased because of the additional benefit to provide clean energy to the proposed development.

The large attendance of the first ever ocean energy workshop is a clear indication of the growing interest in wave energy development in South Africa.

Acknowledgements

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