International Journal of Mechanical and Industrial Engineering

Volume 3 | Issue 2 Article 2

October 2013

WAVE ENERGY CONVERSION AN EMERGING MODE OF RENEWABLE AND SUSTAINABLE POWER GENERATION

DIGVIJAY SINGH RAGHUVANSHI
Bharati Vidyapeeth Deemed University College of Engineering, Pune, India, raghuvanshidigvijay@gmail.com

JAYESH L. MINASE
Singhad College of Engineering, Pune, India, jlminase@gmail.com

WAVE ENERGY CONVERSION AN EMERGING MODE OF RENEWABLE AND SUSTAINABLE POWER GENERATION

DIGVIJAY SINGH RAGHUVANSHI & JAYESH L. MINASE

[1]Mechanical Engineering, Bharati Vidyapeeth Deemed University College of Engineering, Pune, India
[2]Mechanical Engineering, Singhad College of Engineering, Pune, India
e-mail: raghuvanshidigvijay@gmail.com, jlminase@gmail.com

Abstract— Ocean waves, if employed efficiently for generation of electricity, could result in the most economic green process (minimal carbon emission). This paper, *based on the extensive literature survey conducted as a part of a B.Tech Project* provides an overview of the current scenario of power generation and consumption in India thereby emphasizing on the progressively increasing power requirement and a lagging behind share of renewable energy. A scientific clarity is drawn on the basic theory behind wave generation and the key factors for assessing and deploying wave energy converters. Further, a few successful wave energy conversion techniques are discussed briefly, which posses the potential scope of future research and development and are presently employed under pre-commercial and commercial stages around the globe. A special emphasis is laid on the *point absorber* section which has been the area of research for the authors' project thereby detailing its constructional and working aspects and also discussing briefly an experimental procedure to set up a wave generator, to calculate *mechanical conversion efficiency*, and its scope of applicability. The conclusion is drawn in favor of the coastal communities which still rely on costly diesel for generating electricity.

Keywords*- Ocean Waves, Power Generation, Wave Energy, Wave Energy Converters.*

I. INTRODUCTION

Initially, hydroelectric dams were the only known mass-producing water-based sources of energy, but with almost three decades of intensive research and developments, capturing the energy of ocean waves in offshore locations has been demonstrated and proven as technically feasible. In comparison to other renewable energy sources such as the solar or the wind, an ocean wave provides energy with the highest power density and is available day and night throughout almost the entire year [34]. Thus, if harnessed efficiently, wave energy conversion could be the best and most economical way of generating green electricity. Most importantly, India, having a coastline of about 7,500 km, has got abundance of this energy, ready for harnessing**.**

II. ENERGY SCENARIO OF INDIA

Electricity, a major ingredient for the growth of any economy, is a concern in a country like India. India being the second largest population and abode of around 15% people of the world has a large appetite of energy. Since its transformation into a production hub, a major part of world manufacturing has shifted here which has considerably escalated the consumption within recent years.

A. Electricity Consumption Status

The total percentage of Indian domestic energy consumption has grown from **16.9% to 24%** due to urbanization and rise in service sector [2]. Demand for electricity in India far outstripped availability even in 2011 when the base load requirement was 861,591MU against availability of 788,355MU, 8.5% deficit. During peak loads, the demand was 122GW against availability of 110GW, a **9.8% shortfall** [3]. The estimated demand in the power sector in the near years 2016–17 is expected to be at least 1392 Terra Watt Hours, with a peak electric demand of 218 GW [4]. The main cause for this prorogation is the increasing quality of urban life as well as the industrial growth [5]. Besides, there is a constant problem of transmission and distribution losses. In 2011 itself the **TND losses** were reported to be 24% of the total generation [6].

B. Electricity Generation Status

Fig. 1, Indian power generation capacity hit the mark of **186654.62MW in 2011**, 65% of which was based on fossil fuel, maximum contribution being played by coal based thermal (about 53%), and natural gas (about 11%) [7][8]. Apart from carbon emission due to these depleting resources, a large import requirement also affected the economy (18% of the total coal was imported in 2010) [9]. Vision for augmentation of nuclear power from present 4.2% to 9% in 25 years faced severe civil agitation in many parts of the country due to major risks involved [10].

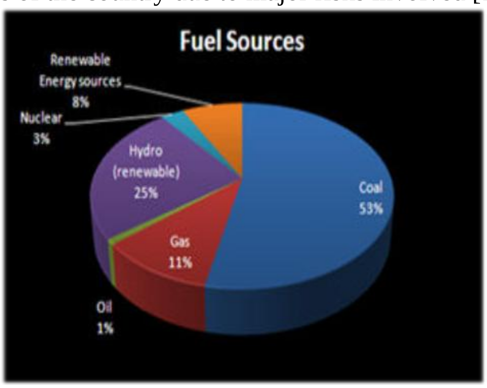

Fig. 1. Electricity Generation Status of India [7]

Hydroelectric power generation was 21.76% of total but has minute prospects of future development [11]. The focus diverts to the fact that negligible research in any wave energy conversion techniques has been done in India to increase the share of renewable power.

III. SALIENT FEATURES OF WAVE ENERGY CONVERSION

Ocean waves have the highest energy density, high availability factor (almost 90%) [1], uninterrupted supply throughout the year (day and night), continuous and predictable in nature and a natural seasonal variability to suit the climate-dependent electricity demand [13], lowest environmental impacts during construction, installation, operation and electricity production [14], almost negligible land usage, no fossil fuel requirement or related capital investment (mining, transportation, processing, etc.), no carbon emissions or greenhouse gases, a simple power generation process free from complex or hazardous equipment or material eventually decreasing the risk of fatal accidents or even small scale loss of life, property, land or economy and a high capacity potential (60MW to 100MWs from a stretch of 1km wave farm or more), etc. are the major advantages [12]. Most importantly, India, having a coastline of about 7,500 km, has sufficient potential to utilize the ocean energy.

IV. WAVE ENERGY CONVERTERS

The transfer and concentration of energy from the wind passing over the ocean surface generate viscous shear and dynamic forces at the wind-water interface which cause a gravity wave to form and grow, leading to the production of an ocean wave energy spectrum. These high energy ocean waves can propagate across thousands of kilometers of deep-ocean with little attenuation [1]. A wave energy converter (WEC) is a device that absorbs energy stored inside the ocean wave and transforms it into some form of mechanical energy. This mechanical energy is then converted into usable electricity using a power take-off (PTO) mechanism that is housed either inside or outside a WEC. Based on its operating principle, a WEC can be divided into four main types: the oscillating water column, the overtopping body, the articulated attenuator and the point absorber. The selection of a particular type of WEC depends not only on the conversion efficiency required, but also on the operating bandwidth (amplitude and frequency of incident ocean wave). In addition, the operating conditions, which affect the stability and survivability of a WEC, need to be considered as well. Moreover, the location of a wave farm is also of significance because the wave resource is generally greater in offshore than in shallower seas. Therefore, an optimum balance needs to be struck for the lowest cost of electricity to be delivered.

A. Oscillating Water Column (OWC)

It consists of an enclosed chamber (air conductive) within a structural housing (concrete or steel) which is partly submerged. It is designed and sized in accordance with the local wave characteristics (wave period, length and height), and is placed above the sea water level, either on the shoreline (where waves strike) or offshore (housing moored fixedly or slack to the ocean bottom) [19]. Fig. 2, the change in water level inside the air chamber, due to crests and troughs in incident waves, induces air pressure variations within the housing via bidirectional air flow through an axial flow Wells Turbine placed on top of the housing. The turbine rotates in the same direction irrespective of the air flow direction. An electrical generator coupled to the turbine produces electricity. Protruding chamber walls in the direction of waves enhances wave collection [18], [20], [21], [23].

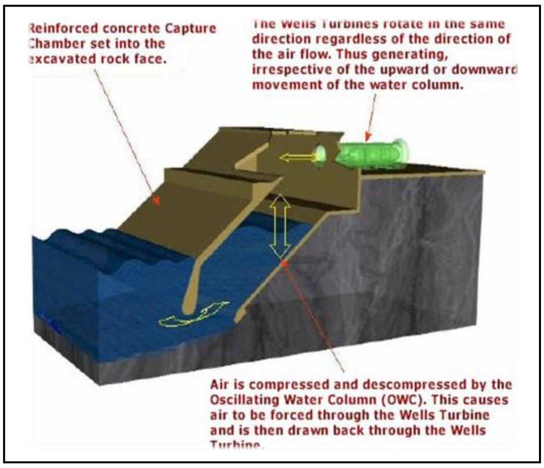

Fig. 2. Oscillating Water Column [27]

B. Overtopping Device:

Incident waves of sea water are captured and collected in a reservoir by a large pair of curved reflectors which gather waves into a central receiver. From there, the water flows up a ramp-like platform over the top of the reservoir and is channeled back into the sea by various low-head turbines. The turbines are coupled to electrical generators for producing electricity [19], [18]. These devices, like OWC, can be slack/fixedly moored to the sea bed [18].Fig. 3, Wave Dragon is a suitable example [22], [23].

C. Point Absorber:

These devices extract energy from all directions around themselves at one point in the ocean by heaving motion of a float (above or below the water surface). The heaving motion is converted, by mechanical or hydraulic system or a combination of both the systems, into a linear/rotary motion which further drives the suitable electrical generator coupled to it [18], [19]. Fig. 4, the Swedish heaving buoy is an example. Limiting the stroke length of float within permissible design parameters to resist extreme wave heights is the major concern which is usually achieved by submerging the float under water with suitable pressure differential techniques[21], [24], [25]. The translator of the generator has springs which stores energy during half wave cycle (crest) simultaneously acting as a restoring force during wave trough. The wavelength of the largest wave, which is to be utilized efficiently, should be known or calculated in order to come up with the suitable device size, rope size as well as the scope of translator reciprocation inside the generator along with suitable compression springs. The design objective is always to approximate the frequency of floater oscillations to that of wave.

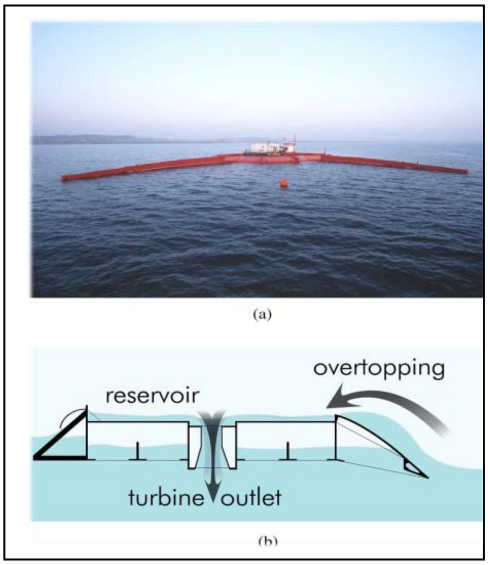

Fig. 3. Overtopping wave energy converter – Wave Dragon [28], [29]

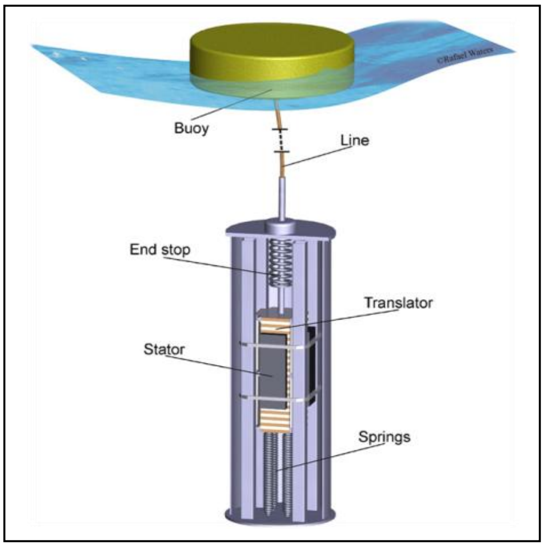

Fig. 4. Swedish heaving buoy with linear electrical generator (courtesy of Uppsala University) [18]

The cables from various power buoys within a stretch of 1km (wave farm), usually in multiple rows of two or three units, side by side, with no gap in between the rows can be connected to a common sub-station underwater. Then, the combined energy (mechanical) of all the floats, of all the rows, would be concentrated on to a single point to operate an electrical generator which will deliver a substantial capacity depending upon the total mechanical input from all the buoys.

The research carried out by the authors as a part of the B.Tech Project was aimed at developing a small scale prototype of a wave generator inside a wave tank to simulate a point absorber wave energy converter functioning, specifically focusing on a methodology for obtaining the mechanical conversion efficiency for a desired float shape with varying weights or sizes.

Fig. 5, Modern tanks usually use either flap paddles or piston paddles for generation of waves. A piston paddle displaces double amount of water as a flap with the same stroke, resulting in a wave which is approximately twice as big as in the case of a flap paddle [36]. Since our tank is a short length structure, hence smaller waves from the same stroke is preferable which indicates towards the selection of a flap paddle system.

The generation of waves inside the tank is due to repeated reactions of a water column from a vertical plate placed at one end of the tank (inside the tank) such that the face of plate is parallel to the vertical face of that end of the tank. Fig. 6, The Galvanized Iron plate is of dimension 49inch*29inch with small square slots cut from the corners of the base edge to provide scope of support while mounting. A strip portion of the G.I plate is bended and riveted to the remaining plate to provide a heavy base as -

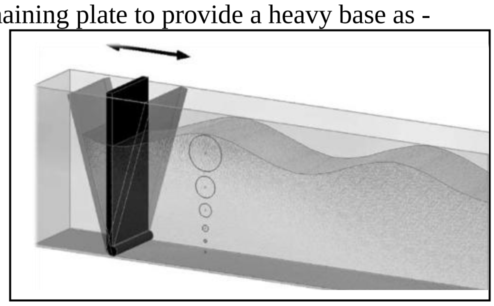

Fig. 5. Schematic of a Flap Paddle [36]

Fig. 6. G.I. Metal Wave Plate (49inch * 29inch)

well as providing a long slot (kind of subway) for a steel rod which will act as the main support for plate mounting and will also provide the inverted pendulum motion of the plate about the base. The ends of this support rod are further supported by pieces of wooden blocks stick to the base of the tank. These blocks are drilled along their central axis along their length so that each block provides a central penetration for each end of the support steel rod through them.

Fig. 7, an open mild steel tank of dimension 6feet*4feet*3feet provides sufficient capacity to hold water and suitable apparatus involved. In regards with the standard researches done, the design of the tank depends upon the stroke of the paddle and the type of research to be carried out, but ultimately the budget decides.

To generate oscillations of wave plate the source of energy is an A.C motor (230V AC Induction Motor and power 8HP) which is a geared motor to provide low and variable RPM (0 – 150) along with a high torque. Fig. 8, A slider crank mechanism to transfer the power from motor to the wave plate is selected having crank as a cast iron bar of length 11inch approx. (rotating radius = 5.5 inch approx.) whose centre is fixed on the rotating motor spindle. The dimension of crank restricts the scope of reciprocation of the wave generator plate. As the desired angle of oscillation of the plate is anywhere between 10 and 20 degrees, and the height being 29inch approx., therefore the oscillation amplitude of the top edge of the plate ranges around 10 to 11 inches.

Fig. 7. Mild Steel Tank (6 feet * 4 feet * 3 feet)

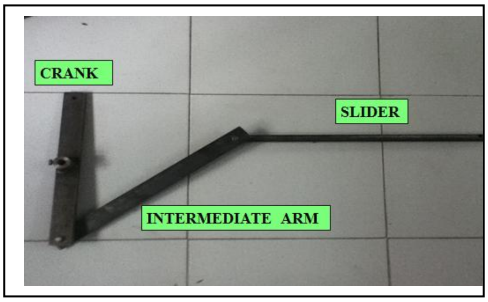

Fig. 8. Slider Crank Mechanism

An intermediate arm is a bar of length 12inch approx having one end connected to the crank and the other to a slider. A slider is a rod of length 15 inch approx. and diameter 1.5cm approx reciprocates inside a bush supported by the support frame. One end of the rod is connected with the intermediate arm and the other is fixed with the wave plate's tope edge at its approximate centre.

Fig. 9, a frame supports the mounting of the motor such that the height of the reciprocating slider and the height of wave plate's top edge are in close margins with each other. By intense literature survey and analysis of previous shapes applicable in the presently deployed prototypes, an oval shape point absorber was a suitable choice. Fig. 10, to produce sufficient slamming forces on the bottom of float to produce maximum scope of upward thrust as well as to produce optimum buoyancy we have taken a pair of oval domestic open bowls made of plastic and fixed them from face to face from open ends after applying suitable -

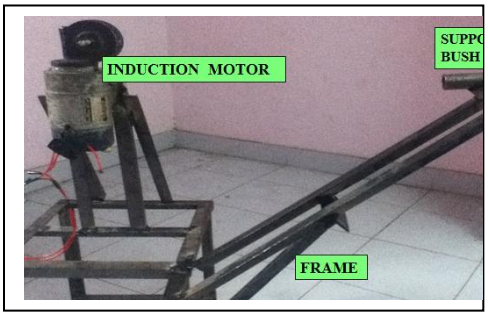

Fig. 9. Metal Support Frame and Motor Assembly

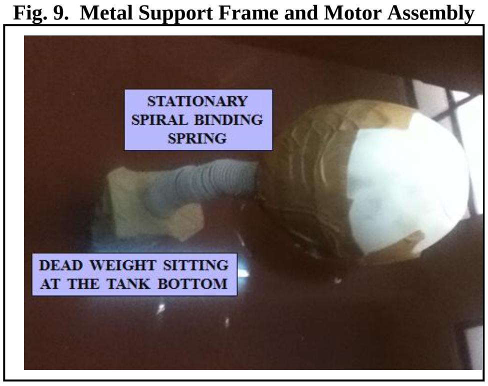

Fig. 10. Float Set-Up

fixed weights inside them to maintain the centre of gravity of the float system. Fig. 10, the bottom of the float is linked with a heavy weight element, which rests at the bottom of the tank, by means of commercial binding springs used for notebook binding that will somehow facilitate the environment of the springs of a linear electrical generator and give a closer-to-real simulation of the float motion. The position of float from the paddle must be approximately twice the hinge depth (the depth of the hinged point of the wave generator plate from the mean water level) [36].

Once the system starts, the RPM value of rotating crank can be interpreted even manually. Fig. 11, from the crank, the motion is transferred to the slider by means of the intermediate arm. Fig. 11, the slider reciprocates inside the bush such that the reciprocation produces oscillation of the connected plate edge thereby producing an inverted pendulum motion to the entire wave plate which is hinged at the bottom. Fig. 12, the oscillations of wave plate produces repeated reactions of its surface with the column of water in contact, thereby generating continuous wave ripples. These waves travel from one end of the tank to the other, losing energy constantly in their path of travel. The amplitude of generated waves can be determined simply by a level measurement device/mechanism.

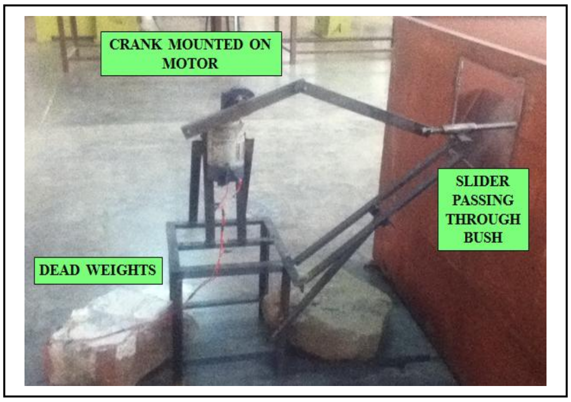

Fig. 11. Slider Crank Mechanism Mounting on the Support Frame

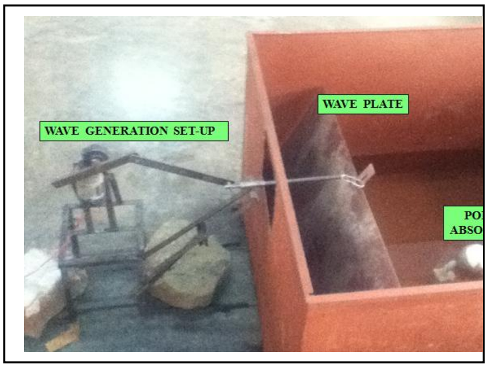

Fig. 12. Final Prototype of the Project

The point absorber is kept as close as possible to the origin location of waves in tank such that maximum amount of energy is contained in waves when they intercept the point absorber float in their path.

The float oscillates in proportion to the incoming wave energy and the amplitude of these oscillations is measured. Thus the mechanical conversion efficiency can be successfully analyzed which is basically the ratio of the average amplitude of float oscillations to the amount of incident energy that was incident on the float for a fixed shape and weight.

By varying the RPM of motor, we can vary the frequency of oscillations of wave plate and accordingly the generated amplitude of waves. Hence, for a particular rpm value, there will be incident wave amplitude and proportionally produced amplitude in float. We can then calculate the mechanical conversion efficiency for each of such combination and find out that set for which the efficiency is maximum, which is equivalent to simulating different sea climate. Similarly, we can fix the motor rpm and vary the physical parameters of the point absorber float such as mass, shape, size and find the most efficient set of combination which is nothing but improving the cost effectiveness of the final prototype that will be deployed.

As an approximate guide a flap paddle should extend about 35% of the hinge depth above the waterline as per the engineering solution to wave generator design, hence the water level decided [36]. Since distance of the float from paddle is twice the hinge depth i.e. 1060 mm, hence the water level (H) decided is 540 mm and at an RPM of 48 and float mass of about 100 gm the average of one of the set of readings was obtained as follows:

TABLE I
OBSERVATION FROM EXPERIMENT

Parameter	Assigned Variable	Calculated Value (approx. in mm)
Observed Average Wave Height from Tank bottom at crest	H1	712.5 mm
Observed Average Wave Height from Tank bottom at trough	H2	420 mm
Average Wave Height Considered (crest to trough)	(H1 – H2)	292.5 mm
Observed Average Height of Point Absorber from Tank Bottom at no wave condition	P	625 mm
Observed Average Highest Height of Point Absorber from Tank bottom in wave propagation	P1	726 mm
Observed Average Lowest Height of Point Absorber from Tank bottom in wave propagation	P2	583.5 mm
Displacement of Point Absorber Considered	(P1 – P2)	142.5 mm
Mechanical Conversion achieved	{(P1 – P2)/(H1 – H2)}*100	48.72 %

There are reflected waves coming towards the float from the end of tank opposite to the wave generator end which contribute to give additional mechanical energy to the float and hence an enlarged amplitude of the float. This is majorly due to the insufficient length of the tank. The solution lies in as many ways imaginable ranging from an increment in the length of the tank so as to die out/exhaust all the energy of wave in the travel, or set up a “beach-like” model at the other end of the tank so as to provide reaction forces to the incoming waves which will consume their energy [36]. Also, the ripples caused by wave breaking can be minimized by covering the sloping beach surface as well as side surfaces by a layer of foam or mesh material.

Due to financial constraints, unfortunately the dimensions of the tank could not be dealt with and was a point of severe consideration before going for the experimentation because of the expected outcome. Since the size and the reliability of electronic drives have improved dramatically, they can be used along with hydraulic drives as well instead of a crank driven wave generator. In that way one can control the paddle motion more accurately by a signal generated to give a wider range of data for analysis.

However, the project's sincere effort is to propose initiation and acceleration of research in wave energy conversion in the Indian subcontinent even at university level. In fact the flap paddle can be implemented to model all kinds of floating structures as well as study the sea water physics and subsequently model the sea conditions whereas simultaneously being flexible and economic enough to test other domains of wave energy converters as well.

D. Pitching Device:

It consisting of a number of hinged together floating structures, having their principal axis (length) in the direction of wave propagation. The relative motion between the structures pumps high-pressure oil through hydraulic motors, thereby driving the coupled electrical generators. Fig. 13, the Pelamis is a suitable example, [23],constituting a linkage of hinged joints of cylindrical sections which heave and sway, due to induction of wave motion, to pump high pressure hydraulic oil through hydraulic motors to drive the generators, along with a flexible slack-mooring system to retain position or swing relative to incoming waves [19], [21], [18].

Fig. 13. Pelamis [31]

VI. CONCLUSION

Approximately 8,000-80,000 TWh/yr or 1-10 TW of wave energy is estimated to be in the entire ocean and each wave crests transmits 10-50Kw/m on an average [14]. An estimate in 2004 claimed the expiry of global oil and gas reserves within 45 years and 65 years respectively [9]. The continuously increasing gap between the demand and supply of electricity in India effects industrial and economic growth. The increasing industrialization, urbanization, population and global warming hence calls for an urgent need to speed up the building of emission free sources of energy in India. This will eventually require intensive research and development in wave energy conversion technology, considering its advantages over other renewable energy sources and the available untapped wave potential along the extensive coastlines of India. Such measures would open the gates for effective commercialization of wave energy in India as well as attracting a new kind of tourism revenue at many popular coastal regions while simultaneously paving way for an entire new domain of employment and job opportunities.

REFERENCES

[1] Ringwood, J., 2008, 'Practical challenges in harvesting wave energy', ECOR Symposium. St. John's Newfoundland.

[2] CMIE, D&B Industrial Research Service.

[3] "Load Generation Balance Report 2011-12'' Central Electricity Authority/ Government of India.

[4] "Report on 17th Electric Power Survey of India" CEA, Ministry of Power 2007.

[5] "Powering India: The Road to 2017" Mckinsey 2008.

[6] "TND of Electricity in Regulates, Investment & Efficiency" OECD.

[7] India Energy Data, Statistics and Analysis (2009)

[8] "Power sector at a glance: All India data". Ministry of Power, Government of India. October 2011

[9] "Indian Power Plant Coal Imports news" Source: Market Watch

[10] "Slowdown not to affect India's Nuclear Plants; Business.standard.com2009-1-21 Retrieved 2010-8-22

[11] Power sector at a glance "All India" 31-12-2011 Source: Central Electricity Authority.

[12] Power India Technologies Pruthvi's "Ocean Energy – A eco-friendly source of power" under 'Pollution and Global Warming'.

[13] "Wave energy in Europe: Current Status and Perspectives" et al . By Alain Clement , Pat McCullen , Antonio Falcao, Antonio Fiorentino, Fred Gardner, Karin Hammarlund, George Lemonis, Tony Lewis, Kim Nielsen, Simona Petroncini, M.Teresa Pontes, Phillippe Schild, Bengt-Olov Sjostrom, Hans Christian Sorensen, Tom Thorpe, (2002) Published by Elsevier Science Ltd.

[14] Thorpe TW. "A brief review of wave energy". A report produced for the UK Department of Energy. Report No ETSU-120; 1999. Available online at:

http://www.mech.ed.ac.uk/research/wavepower/Tom%20Thorpe/Tom%20Thorpe%20report.pdf

[15] Power Buoys: Electricity from Waves. The Economist May 2001. Pg 78-79.

[16] Falkovich, G. (2011), Fluid Mechanics, a short course of physics, Cambridge University Press, ISBN 978- 1-107-00575-4

[17] "A good illustration of wave motion according to linear theory" by Prof Robert Dalrymple.

[18] "Ocean Wave Energy Conversion – A Survey"- A. MUETZE, J. G. VINING. Electrical and Computer Engineering Department. University of Wisconsin-Madison (2005).

[19] Alcorn R, Hunter S, Signorelli C, Obeyesekera R, Finnigan T, Denniss T. Results of the testing of the Energetech wave energy plant at Port Kembla. Energeth Report; 2005. Available online at: http://energetech.com.au:8080/attachments/Results_PK_Wave_Energy_Trial.pdf.

[20] "A review of wave energy converter technology". B Drew, A R Plummer, and M N Sahinkaya. 2009. University of Bath, Bath, UK.

[21] Kofoed JP, Frigaard P, Friis-Madsen E, Sørensen HC. Prototype testing of the wave energy converter Wave Dragon. Renewable Energy 2006; 31:181–9.

[22] McCormick M. Ocean wave energy conversion. Wiley, 1981.

[23] Ross D. Power from the waves. Oxford University Press, 1995.

[24] Budal K, Falnes J, Iversen LC, Lillebekken PM, Oltedal G, Hals, et al. The Norwegian wave-power buoy project. In: Berge H, editor. Proceedings of 2nd International Symposium on Wave Energy Utilization, Trondheim, Norway; 1982, p. 323–44.

[25] Nielsen K, Smed PF. Point absorber—optimization and survival testing. In: Proceedings of 3rd European Wave Energy Conference; 1998. p. 207–14.

[26] Falnes, J. A Review of Wave-Energy Extraction. Mar. Struct., 2007, 20, 185–201.

[27] Chris Carroll, "In Hot Water," National Geographic, vol. 208, no.2, Aug. 2005, pp. 72-85.

[28] Richard Boud, "Status and Research and Development Priorities, Wave and Marine Current Energy," UK Dept. of Trade and Industry (DTI), DTI Report # FES-R-132, AEAT Report # AEAT/ENV/1054, United Kingdom, 2003.

[29] "Waves and Swell," NOAA Library's Oceanic and Atmospheric Sciences, http://www.lib.noaa.gov/docs/windandsea6.html#waves, (current 1 Dec. 2005).

[30] "OCEAN ENERGIES: RESOURCES AND UTILISATION" M. TERESA PONTES AND ANTONIO FALCAO.

[31] Pelamis. Available from http://tinyurl.com/pelamis

[32] Teresa Hansen, "Catching a Wave," Power Engineering, http://pepei.pennnet.com/Articles/Article_Display.cfm?Section=Articles&ARTICLE_ID=238327&VERSION_NUM=2&p=6 (current 1 Dec. 2005).

[33] Wave Energy: Physics and Resource

[34] World Energy Council, 2007, Survey of Energy Resources.

[35] http://ocsenergy.anl.gov/images/photos/wave.jpg

[36] Ocean Wave Energy – Current Status and Future Perspectives – Joao Cruz

◈◈◈