



Application of Renewable Energy Using Non-Linear Oscillation Technique in Mechanical Engineering

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Abstract

Deep waves are a giant, mostly untapped energy resource, have the prospective for extracting energy from surfs is significant. Investigation and study in this region is motivated by the requirement in order to fulfill the targets of the renewable energy, however is comparatively immature in comparison to the various other forms of renewable technologies. The analysis introduces the general statutes of the wave energy as well as evaluates the type of the devices that represent WEC technology (Wave Energy Converter), principally focusing on work being undertaken. The anticipated review will explicitly demonstrates the primary projects of wave energy conversion worldwide at multiple levels. Specifically, mooring will be deliberated, as it is regarded as the primary feature behind the considerable deployment of the wave energy converters. Lastly, the research will cater the problems that have to overcome by the wave energy converters in order to become commercially economical within the open market of energy.

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Introduction

Despite being discussed in patents since the advent of the 18th century, contemporary research into harnessing energy from waves was enthused by the emerging oil crises of the 1970s (Bowen, 2014). With the attention of the globe, has now been drawn to the climate change as well as rising level of CO₂, the focus on producing electricity from the renewable resources has been once again become the significant area for research (Yoon, 2012). The global power resource of the wave energy is projected to be at least 1TW. The potential energy production is estimated to be 2000 TWh, this is analogous to the production from hydropower or nuclear.

The present research aims to provide an update regarding the latest trends in the wave energy conversion schemes worldwide at diversified levels such as; demonstration stage, commercialized, and in prosecution projects with respect to the previously accomplished researches (Yan, 2014). Particularly, mooring will be conferred, as it is regarded as the primary feature behind the considerable consumption of the wave energy converters. In addition to it, the review will highlight the challenges that need to be astounded by the wave energy converters in order to become commercially cutthroat within the international market.

Background

The below mentioned figure displayed an atlas of the worldwide destruction of the power density of oceans (Betts, 2013). The south and north temperature precincts possess the most

suitable sites for capturing the wave power (Zurkinden, 2014). Typically, a wave resource is portrayed in the context of wave crest length (power per meter of wave front).

$$P_{w_f} = (1/8\pi) \rho g^2 A^2 T \quad (1)$$

It can be also regarded as power/ meter crust length (P_{w_mcl}).

$$P_{w_mcl} = (1/32\pi) \rho g^2 H^2 T \quad (2)$$

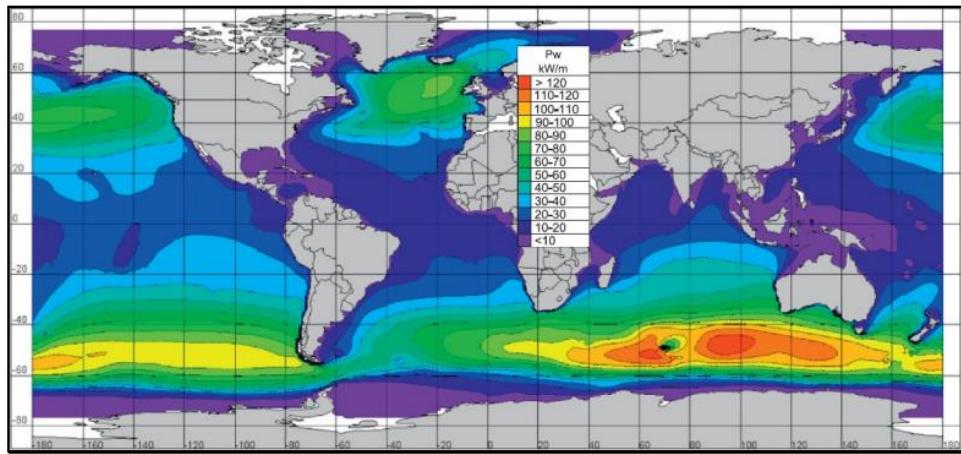


Figure 1: Worldwide Yearly Mean Wave Power Estimation in kW/m straddling 10 years (Gunn and Stock-Williams, 2012)

Where,

H = Wave height = $2A$.

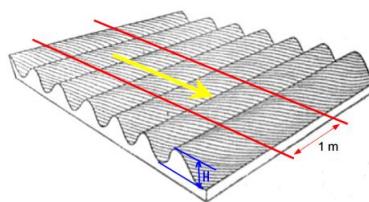


Figure 2: Wave dimensions (Ocean Wave Calculator, 2016)

Literature Review

Wave Energy Converters (WECs)

The purpose of the development of WECs is to extract energy from shoreline out to abyssal water offshore. Generally, such devices are classified by PTO (Power Take-Off) and installation location (Harne, 2013). Locations are near offshore and shore and are shoreline as mentioned in the figure (Zurkinden, 2014). Most of the devices can be distinguished in this context, as belonging to 6 types; i.e. overtopping device, Point absorber, submerged pressure differential, attenuator, wave surge converter, and vacillating water column as illustrated in the figure mentioned below.

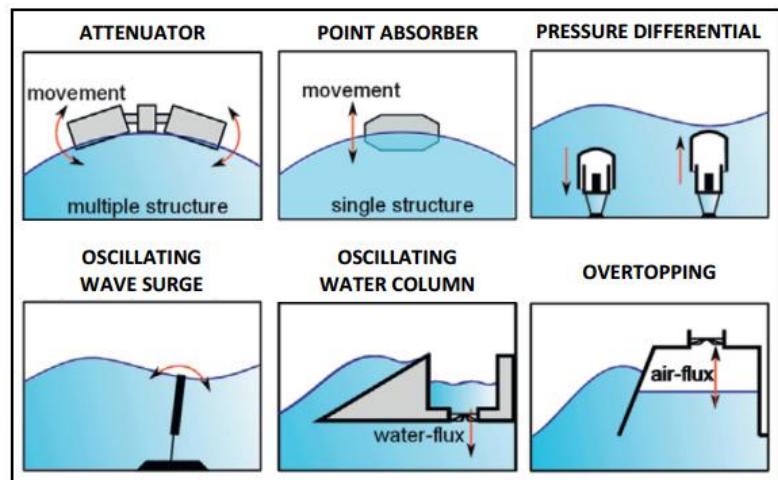


Figure 3: WEC Concepts

WEC Primary Projects

The primary projects of WEC in the context of locations and concepts are summarized in the figure mentioned below. However, the figure only summarizes the chief projects of WEC that have reached to the stage of demonstration (He, 2014). In this specific huge concept of

development, it must be observed a latest French WEC scheme known as EM Bilboquet (Yan, 2014). The PTO excerpts mechanical power because the arriving waves generated via the scheme are conjured of cylindrical buoy descending beside the structure that is partially submerged as mentioned in the figure below (Elvin, 2013). This structure is fabricated by vertical cylinder, attached within flowing as wrangle, along with damping plate linked to the capsize (Harne, 2013). Energy that has been generated from the comparative motion amid two concentric bodies is hitched via rack-and-pinion that energies enduring magnet synchronous generator via gearbox.

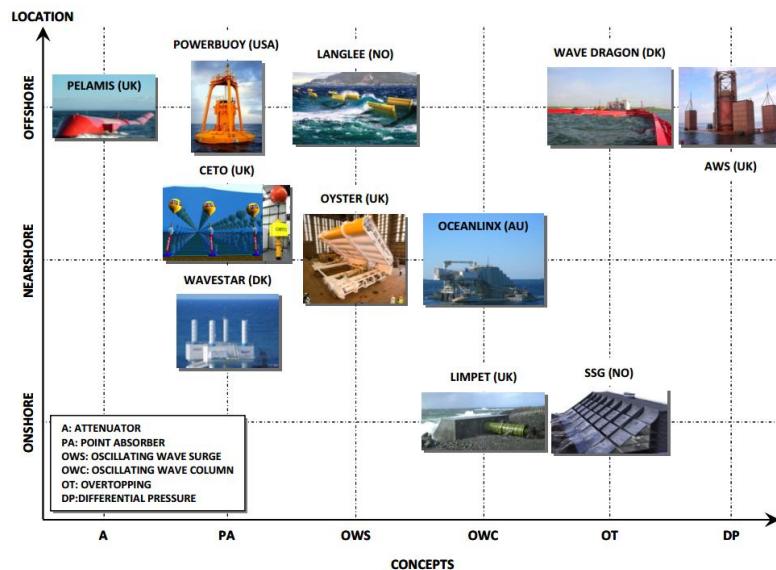


Figure 4: Primary Projects of WEC (Twidell, 2015)

Wave Energy Extraction

The below mentioned figure summarizes the wide range of conversion stages. Specifically, this image display the diversified customs to excerpt power from the waves; mechanically, pneumatically, and hydraulically (PTO) (Gómez-Expósito, 2016). This mechanical edge is deployed in order to transform the reciprocating motion or the slow gyratory

speed into high-speed rotating movement for correlation to a conservative gyratory electrical generator. Regarding this phenomenon, the focus will be on means that is required to change tidal energy into electricity (Elvin, 2013). Reason being, many building blocks within the generation system continue to be similar after being converted into the form of electricity.

Linear generators are regarded as a preference upon the testing phase; however they are not however, presently deployed in many of the urbanized WECs. Particularly, number of types of linear generators was examined with regards to AWS WECs (Brommundt, 2012). These examinations have resulted that good transverse flux permanent magnet generator is regarded as the appropriate candidate in the context of efficiency and higher power density (Cerveira, 2013). The deployment of the permanent magnet synchronous generator is a transitional choice. Also, the application of the induction generators indicates a particular mechanical PTO which, catalogs surplus losses upsetting the in general, efficiency of WEC. In this regard, there still exist challenges to the mechanical engineering with regards to offshore suitability of electrical generator (Zurkinden, 2014). The below mentioned table summarizes the electrical generator options as well as the PTO systems for some of the WEC projects mentioned in the above figure 4.

WEC	PTO	Generator
PELAMIS	Attenuator/Hydraulics	Cage induction generator
POWERBUOY	Point absorber	Permanent magnet synchronous generator
WAVESTAR	Point absorber/ Hydraulics	Permanent magnet synchronous generator
SEAREV	Point absorber	Permanent magnet synchronous generator
BILBOQUET	Point absorber	Permanent magnet synchronous generator
OYSTER	Oscillating wave surge converter	Cage induction generator
ANGLEE	Oscillating wave surge converter	Permanent magnet synchronous generator
LIMPET	Oscillating water column & Wells turbine	Cage induction generator
OCEANLINX	Oscillating water column & Denniss-Auld turbine	Cage induction generator
PICO	Oscillating water column & Wells turbine	Doubly-fed induction generator
WAVE DRAGON	Overtopping & Kaplan turbine	Permanent magnet synchronous generator
SSG	Overtopping	Permanent magnet synchronous generator
AWS	Direct drive	Linear permanent magnet generator

Table 1: Some WEC Projects Generators and PTOs.

Wave Energy Convertor Mooring

The deployment of the wave energy for the generation of electricity, the mooring of the WECs should be with the cables and anchoring with the seabed as shown in below mentioned figure.

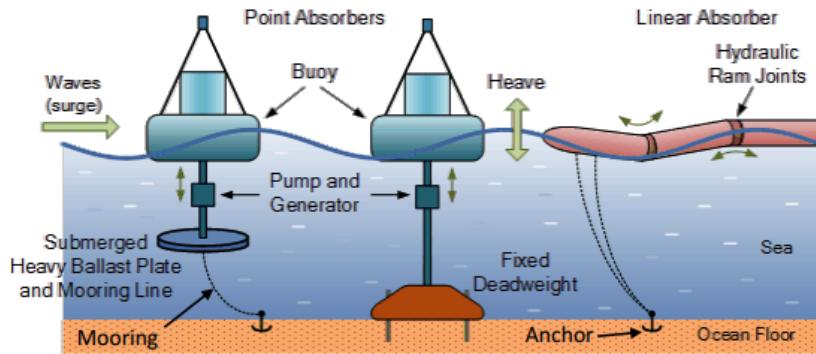


Figure 5: Wave energy convertors anchor and mooring

The typical WEC mooring system is structured with three segments; the anchor, the mooring line, and connectors. Whereas, line types that are used for mooring include synthetic fiber rope, chain, and wire rope that are deployed usually in offshore structures (Yan, 2014). Chains are used because they give good abrasion resistant and catenary stiffness. These restraining stiffens, however, may not be suitable for some of the WECs (Elvin, 2013). Reason being, they can creel oscillation motion that is requisite to transform energy. Synthetic ropes have been proven beneficial since, they have a buoyancy property that will lighten the persuasion of weight of the mooring doing operations and are also suitable candidate for the deep-water applications. In addition to it, there are various other connectors used on marine structures and WECs (Brommundt, 2012). Anchors are regarded as the terminal that transfers the forces of the overall system to seabed.

The two primary necessities are included in keeping the stratagem on the station, as well as to be economical at the same time so that the economics of the whole device remain viable (Brommundt, 2012). Specifically, the mooring system is confined to non-linear load situations, highly cyclic, and typically stimulated via incident waves. The mooring system appropriate for the WEC is classified into two primary arrangements; single point mooring, and spread mooring (Bowen, 2014). The spread mooring limits WEC motion along horizontal plane, and henceforth, donor consent to weather-vane. The sort of mooring is perhaps, suitable for the non-directional energy converters (Gómez-Expósito, 2016). Instead, single point mooring permits WEC to weather-vane. Also, there are number of sub-types as listed in the below mentioned chart.

Type	Spread	Single point
Sub-types	Catenary mooring	CALM
	Taut mooring	(Catenary Anchor Leg Mooring)
	Turret mooring	SALM (Single Anchor Leg Mooring)
		ALC (Articulated Loading Column)
		SPAR (Single Point Mooring & Reservoir)
		Fixed tower mooring

Table 2 : Mooring Types

It is however, difficult to select the best before seeing the type, location, cost, and safety of the WEC (Betts, 2013). Though, it can be said that CALM (Catenary Anchor Leg Mooring) within spread mooring and SALM (Single Anchor Leg Mooring) within the category of single point mooring are most admired amongst practical schemes. The figure mentioned below displays some commonly practiced mooring configurations around the world.

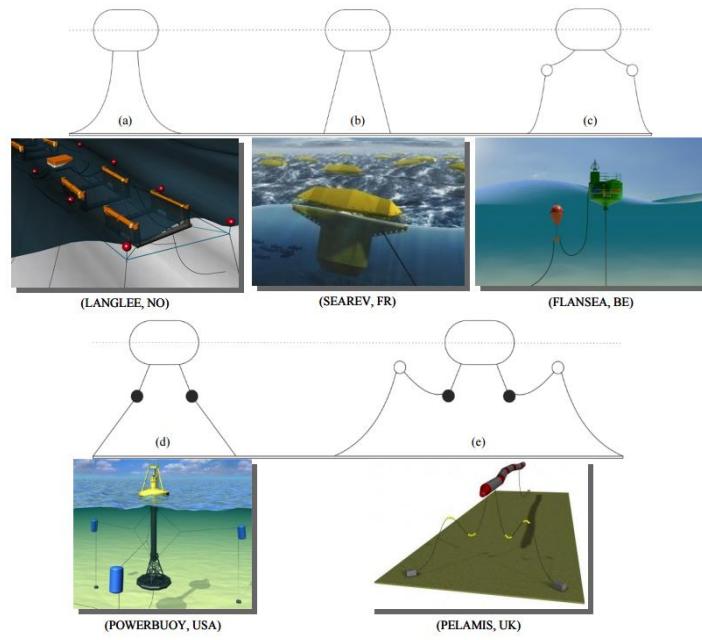


Figure 6: Catenary line; Taut line; Taut line with mid-column float; Taut line with weights and floats (Titah-Benbouzid, 2015)

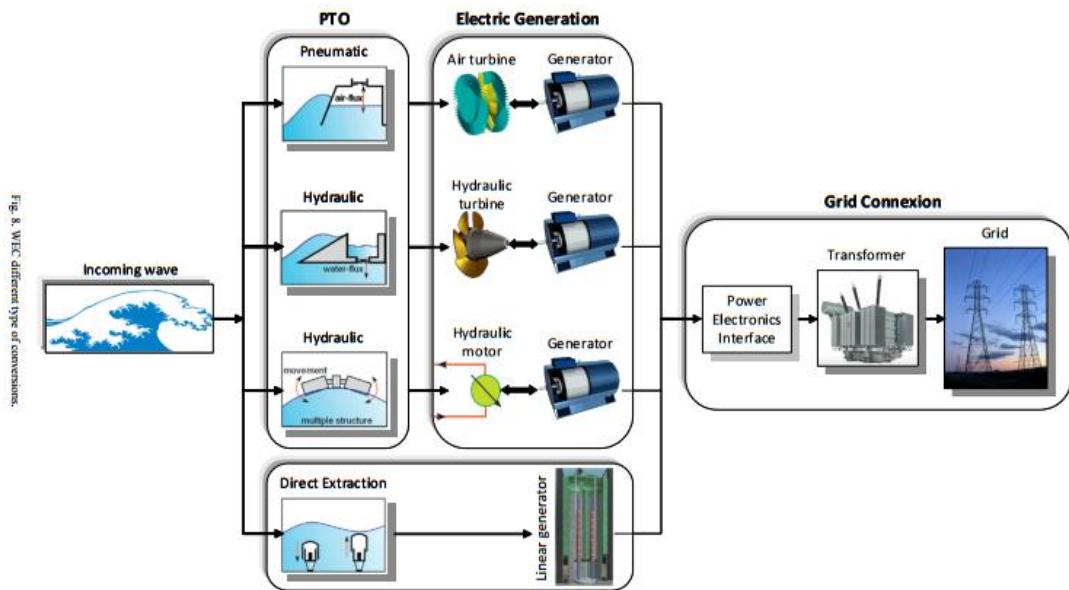


Figure 7: WEC various conversions (Titah-Benbouzid, 2015)

Requirements for the Mooring

The process mooring cannot be regarded as a surplus cost point within entire economics of WEC (Betts, 2013). Rather, it should be aimed as a fundamental constituent of complete system that adds to the competence of the power extraction. With respect to this, the below mentioned list exhibit the requirements that have to be taken under consideration for the WEC mooring systems.

Mooring stiffness can be termed as an effective element in the principle that is used of the wave energy conversion (Brommundt, 2012). The mooring system must be adequately stiff to;

- Avoid constraints in power cable and lines in every tide conditions
- Station keeping within particular tolerances (Yoon, 2012).
- Allow berthing for maintenance and inspection
- Maintain clearance distances amid mooring

It must be adequately acquiescent to environmental loading in order to ease force acting upon mooring lines, anchors as well device itself to the minimum (Yoon, 2012). Also, it must be adequate to put up the tidal arrays at the site of the installation. Hence, it is evident that mooring design is regarded as the perilous element of WEC project. Generally, the strategies are considered to be deployed within the regions of the challenging environmental loads because of wind, waves, and current (Zurkinden, 2014). These concerns of survivability are highlighted in current offshore standards including DNV-OS-E301.

Discussion

The discussion will incorporate the benefits and challenges regarding the application of renewable energy using non-linear oscillation technique in mechanical engineering. The analysis will also be accompanied by the challenges for viable feasibility. The cost benefit analysis will also be incorporated regarding the generation of electricity.

Environmental Benefits

Wave energy devices crop none of the atmospheric pollutants during their operations commonly linked to the conventional electricity generations, such as; nitrogen dioxides, carbon dioxides (Elvin, 2013). However, there are emanations of such type of gases during the development of infrastructure. The most substantial being linked to the material processing as well as the components manufacturing (Bowen, 2014). The below mentioned table illustrates the contribution of the wave energy towards the reduction of the discharge liked to the generation of electricity.

Issues/ Aspect	Impact
Coastal erosion	Near-shore schemes may disturb coastal erosion through modifying activity of wave, a beneficial effect
Acoustic noise	Noise from near-shore and onshore installations may irritate nearby residents, and can also disturb the livestock (Betts, 2013). Emissions of noise, including those from the offshore installations will be mainly directed into the environment (Yoon, 2012). Hence, are

	unlikely to have significant impact on sea creatures.
Marine biota	While construction of wave power plants may have some effects on the initial stage, installations can have an optimistic effect in the long run by serving as artifices reefs
Hazards to navigation	Easily abated using conventional technology, note that wave power plant projects could serve as an aid to navigation (Zurkinden, 2014).
Device moorings	Potential for impacts such as; if moorings break away, careful construction minimizes this lack.
Sedimentary flow pattern	Alteration in the sediment deposition and transport may occur because of the operation and siting of the wave power plants, flow patterns are challenging to envisage and will need site-specific studies

Table 3: Impact and Aspect of WEC

Challenges for Viable Feasibility

It is established that extraction from the wave energy is striking, reason being, it is more intense spatially than both; solar and wind energy (Harne, 2013). Also, the phenomenon is predictable and continual than wind energy. Conversely, expansion from the concept leading to the commercial stage is proven to be very costly and slow procedure. Certainly, it is challenging to pursue what is accomplished in the industry of wind turbine in which, undersized machines were established at first, and also were consequently scaled-up to the superior and better powers and sizes for deployment on large scale (Gómez-Expósito, 2016).

Indeed, absorption from the ideal wave energy incorporates various type of resonance. It suggests that size and geometry of the WEC are associated to wavelength. Therefore, if pilot plants are chosen for experiencing within an open and deep-sea, they should be structured on a larger scale (Elvin, 2013). In this particular perspective, challenges that should be astounded by WEC in order to become commercially competitive resulting in a massive development can be abridged as mentioned below.

As far as off-shore converters are concerned, WEC should endure extreme wave circumstances leading to overpriced and difficult maintenance processes. As mentioned previously in the research, mooring proposal is regarded as the challenging part. Over and above to the arduous ecological loads because of current, wind, and waves, mooring system should also endure restraints because of the configuration of WEC for apprehend optimization (He, 2014). Providing the constant environmental loading, exhaustion is reported as one of the primary confrontation to the engineering. Moreover, corrosion and marine growth required to taken into consideration.

Higher cost of deployment, maintenance, and construction should be reinforced with considerable financial support from the higher authorities and the government. For the cost issues and the fatigue, it erstwhile recently recommended to widen WECs without mooring. The established converter consists of capability of station-keeping as well as evasive scheme through diving (Betts, 2013). For keeping the station with a constant bound, a wave glider is espoused as the impetus system as illustrated in the below mentioned figure. Moreover, such systems have the capability to plunge to the specific depth regarding its security within certain emergency situations, such as tsunami and typhoon.

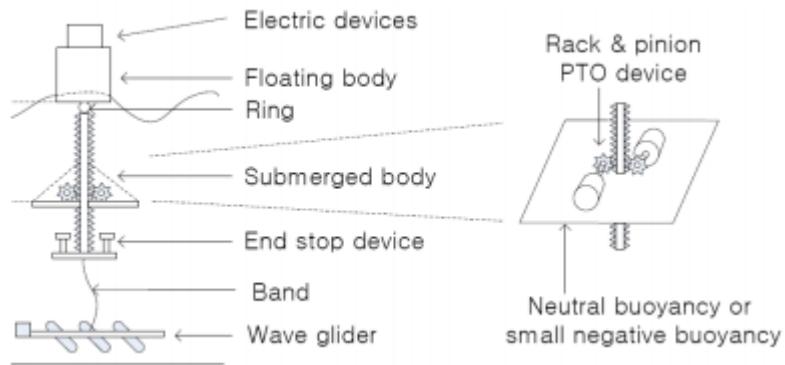


Figure 8: The concept of mooring-less wave energy converter

Comparison of Economics of Electricity Generation

The electricity cost generated from the renewable energy resources depends upon the wide range of factors. Therefore, it is a challenging task to provide a definitive cost for electricity generation unless a plant is specified (Bowen, 2014). The below mentioned table displays that combined wind-wave installation deployed in energetic seas off the US, and UK would be competitive economically with the future costs of that of the photovoltaic and solar thermal plants, as well as completable with the onshore wind installations.

System	Location	Date	Cost (€/kWh)
Solar thermal; parabolic trough	New Mexico, USA	2020	7.5-11
Solar thermal; parabolic dish	New Mexico, USA	2020	6-10
Solar, thermal; central receiver	New Mexico, USA	2020	5-9
Photovoltaic	New Mexico, USA	2020	5-14
Photovoltaic; thin film	New Mexico, USA	2020	6-10
Photovoltaic; multiple thin film	New Mexico, USA	2020	4-7
Wind turbine (6-9 m/s wind spd.)	—	1995	3.6-6.5
Wind turbine (6-9 m/s wind spd.)	—	2000	3-5.5
Wind turbine (6-9 m/s wind spd.)	—	2010-2020	2-4.5
Combined wind-wave system	South Korea	1995	11-18
Combined wind-wave system	UK	1995-1999	6-9

Table 4: Representative Costs from the Renewable Energy Sources

Conclusion

The probability of the generation of electricity from very energy seems to be significant. Ocean is considered as the huge reserve. Therefore, control the energy within ocean waves signifies a vital step towards meeting the targets of the renewable energy. The analysis has introduced the latest status in the context of the renewable technology. A number of devices have been evaluated and established. This research has proposed a converse review regarding the latest trends of the technologies of main wave energy converter with regards to impressions that has been already developed in the recent years. Moreover, mooring has been discoursed as well as key features have been shown that are behind the massive arrangement of wave energy converters. Lastly, it emphasized upon the contests that need to be resolved in order to broaden the apparition of the comprehensive commercial ranges of wave energy converters. In addition to it, individual WECs will often maneuver, therefore, the analysis of the future systems should incorporate the interaction amid the devices.

Recommendations

There is a wide range of the conversion outlines. Though, many of the wave energy devices have been designed and developed; only a small proportion has been evaluated and tested. In addition to it, only few devices have been tested in cornea waves, and at sea rather than in artificial wave tanks. Minor vision for commercial development of wave power is envisioned in most short- to-medium-term conjectures. It will still not be economical, and also the technology remains uncertain. For the respective industry to be successful, standardization of the components and the subsystems is needed that will allow for modularization and will make this industry, ultimately competitive to the various other forms of the renewable power generation.

An accurate assessment of the economics of wave energy must incorporate any fortification of the onshore utility grids that would be essential for the transmission of the wave power to load centers that are aloof far from the best wave resources. Depending upon the cost of the grid reinforcement, this could restrict the development of the amount of energy that would be economically competitive in comparison with various other energy resources.

The cost of the wave energy is less than 10 cents/kWh seems to be feasible for offshore heaving buoy systems cited along costs conquered by the trade wind waves. In today world, WEC are not cost-competitive, on the basis of an avoided energy cost, with the latest utility generated electricity. Very significant developments in capital costs, O and M costs, and the efficiency will be needed to change this condition. Commercial rates of the electricity in most parts of the world are typically higher than that of the utility avoided energy costs.

Conversely, there are also direct uses of the submissions that are cost-competitive in today world upon the small scale. Therefore, more focus should be upon the initial stage development of the on the smaller scale of WECs that give electricity directly to the end user.

These application may give the best prospects for the demonstration and the development of the technology of WEC, such as; shore-based hotel etc. The effective further development in the respective technology needs a committed, and development, commercialization effort, development, and consistent research that are unlikely to proceed without the support of the special authorities and the government.

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