Multi-Criteria Selection and Improvement of Effective Design for Generating Power from Sea Waves

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***Abstract*—**Sustainable development is the nominal goal of most countries at present. In general, fossil fuels are the development mainstay of most world countries. Regrettably, the fossil fuel consumption rate is very high, and the world is facing the problem of conventional fuels depletion soon. In addition, there are many problems of environmental pollution resulting from the emission of harmful gases and vapors during fuel burning. Thus, clean, renewable energy became the main concern of most countries for filling the gap between available energy resources and their growing needs. There are many renewable energy sources such as wind, solar and wave energy. Energy can be obtained from the motion of sea waves almost all the time. However, power generation from solar or wind energy is highly restricted to sunny periods or the availability of suitable wind speeds. Moreover, energy produced from sea wave motion is one of the cheapest types of clean energy. In addition, renewable energy usage of sea waves guarantees safe environmental conditions. Cheap electricity can be generated from wave energy using different systems such as oscillating bodies' system, pendulum gate system, ocean wave dragon system and oscillating water column device. In this paper, a multi-criteria model has been developed using Analytic Hierarchy Process (AHP) to support the decision of selecting the most effective system for generating power from sea waves. This paper provides a widespread overview of the different design alternatives for sea wave energy converter systems. The considered design alternatives have been evaluated using the developed AHP model. The multi-criteria assessment reveals that the off-shore Oscillating Water Column (OWC) system is the most appropriate system for generating power from sea waves. The OWC system consists of a suitable hollow chamber at the shore which is completely closed except at its base which has an open area for gathering moving sea waves. Sea wave's motion pushes the air up and down passing through a suitable well turbine for generating power. Improving the power generation capability of the OWC system is one of the main objectives of this research. After investigating the effect of some design modifications, it has been concluded that selecting the appropriate settings of some effective design parameters such as the number of layers of Wells turbine fans and the intermediate distance between the fans can result in significant improvements. Moreover, simple dynamic analysis of the Wells turbine is introduced. Furthermore, this paper strives for comparing the theoretical and experimental results of the built experimental prototype.

***Keywords*—**Renewable energy, oscillating water column, multi-criteria selection, wells turbine.

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I. Introduction

SUSTAINABLE development has become a major concern of most countries in recent years. Generally, fossil fuel is the main pillar of industrial development. Furthermore, the availability of fossil fuels with sufficient quantities is one of the important factors that help industrial countries in developing their industrial sectors at a rapid pace.

Unfortunately, the fossil fuel consumption rate is very high and does not match with the rate of increasing energy demand in these countries. Also, toxic and harmful emission fumes during conventional fuel burning can be considered as a serious environmental pollution problem [1]. Such serious environmental problems hinder progress efforts in industrial countries. Thus, clean renewable energy has attracted the attention of industrial countries in recent times for compensating the energy shortage in addition to preserving the environment [2], [3]. Clearly, reliance on renewable energy can solve the energy shortages problem but developing its usage needs enough time to meet the future tasks. Some regions around the world are somewhat modest in their resources of traditional energies such as; oil, coal and natural gas. Hence, exploiting additional energy recourses other than fossil fuel must be the main task of these regions for guaranteeing the sustainability of available energy sources for a long time. Thus, regions with poor traditional energies can use many types of clean renewable energy resources such as wind, solar and sea waves for treating their energy shortage. However, the usage percentage of various types of renewable energy is still low. Whereas, consumed renewable energy such as solar, wind, hydro and sea waves is still around 10% from the total energy across the world over the past few years [4].

It is encouraging to note that, some regions in the Middle East, such as the Gaza Strip, are trying to do their best to fill the gap between their available energy and their growing needs using renewable energy, as in [5]. Also, the consumption percentage of renewable energy in Egypt is around 11% from the total energy usage in the last five years. Furthermore, the Egyptian authorities suggested an ambitious

plan to reach a usage percentage 20% of renewable energy from the total energy usage by 2020, as in [6].

Generally, solar energy is only available in the sunny time during the day which does not exceed one-third of total daytime. Hence, the performance of solar cells may fluctuate through the day and during different seasons. Likewise, the active strong wind energy does not steadily exist during the whole day and seasons. Thus, it is impossible to maintain the performance of wind turbines at a constant level. Also, the capability of generating energy from water cliffs on rivers is not available for most countries in the world. In addition, there serious risks that may occur during the power generation process in power plants using nuclear power [7]. On the other hand, generating energy from sea waves is available during most of day-time and throughout the year. Hence, the process of electricity generation from seas waves is considered to be more effective than generation from wind or solar sources. Generally, seas and oceans can be used for generating electricity by many ways such as the use of tidal energy, kinetic energy of moving waves, in addition to usage of temperature variation between warm water content at the surface and cold water near the seabed [4].

There are many alternate ideas dealing with generating power from sea waves, as presented in [8]. Moreover, a prototype of mechanical mechanism which can be used for generating power from sea wave's motion is introduced in [9]. Furthermore, a special technique for converting sea wave's energy to electricity is presented in [3] that deals with the shoaling phenomenon near coasts.

The systems which generate power from sea wave's motion are depending on many operating ideas as; Oscillating Bodies (OB) system, Wave Dragon (WD) system, Pelamis Converter (PC) system, Pendulum Gate (PG) system, Power Buoy (PB) system, Bristol Cylinder (BC) system, Over-Topping Converter (OTC) system and OWC system, as discussed in [10]-[16].

OB system has an immersed oscillating cylinder composed of two parts, the bottom one is fixed with the seabed and the upper part is floating part that can move according to sea wave's motion within the other part through a smooth guide causing relative motion between the two parts that can be transformed into power as indicated in [10]-[12]. WD system consists of two large upward paths that collecting the water of moving waves in huge reservoir which has a foundation in the seabed. This reservoir is provided with a hydro turbine in its base. The passing water inside the turbine generates the rotation motion in turbine's rotor. The PC system consists of a set of semi-submerged cylinders in shallow water. These cylinders are connected to each other by joints. The wave's motion generates a relative motion between these floating cylinders to generate energy by pumping high pressure fluid to activate hydraulic motors connected with a generator, as presented in [13].

PG system is an oscillating gate that has a pendulum motion resulting from wave's motion near coasts. This oscillating motion can be converted to electricity via a suitable generator. The PB system utilizes the rising and falling effect resulting from the wave's motion which moves the buoy for producing mechanical energy to generate electricity. This electrical power can be transmitted to the coast via undersea secure cables. On the other hand, the BC system in shallow water has a floating cylinder connected to a gearbox via two sets of four bars and joints. This gearbox is fixed to the seabed. Up and down motion of the floating cylinder results in a partially rotary motion in the joints which can be transmitted to the gearbox. This motion can activate the connected generator for generating electricity as mentioned in [13]. OTC system is similar to WD system but it has a submerged reservoir connected with the seabed via strong springs allowing the up and down water motion to its reservoir. There is a turbine in the bottom of this reservoir for generating electricity, as presented in [14].

OWC can be constructed at the shore. It consists of a suitable hollow chamber which is completely closed except at the base that is used for collecting moving water from waves using an inclined entrance beside the breakwater. Sea wave's motion pushes the air pocket inside the chamber up and down passing through an appropriate turbine or driving a suitable mechanical system in order to generate electricity, as mentioned in [9], [15]-[18].

The pushed air of the OWC in the chamber passes inside a suitable turbine such as the Wells turbine which can be fixed beside the chamber. Moreover, the drawn air passes through turbine in opposite direction as a suction effect during wave's water returns back to sea. Consequently, the used turbine with OWC must be designed to continually rotate in the same direction regardless of the air flow direction. Thus, Wells turbine is the best selection for this job, where it can rotate continuously in the same direction as mentioned in [8], [19], [20].

Clearly, establishing different systems inside the oceans and seas for generating power must have high endurance and long life time. Through the recent decades, there are many strenuous trials done for designing effective energy converters for generating electricity from oceans and sea waves. But unfortunately, many of these trials have failed because of the harsh operating conditions in seas and oceans in addition to aggressive salty water. For this reason, many researchers do not agree up till now on the definite economical designs of devices which can be used to generate power from oceans and sea waves, regardless of the extensive research in this field [21].

Currently, several systems for converting wave power into electrical power have been discussed to be considered for application. Each of these systems has its advantages and disadvantages. The selection of the most appropriate system for application is a critical decision in the planning phase of power generation projects. In this research, the characteristics for each method have been investigated and the main criteria for assessment of these methods have been highlighted. A multi-criteria model has been developed to support the decision making process concerning the selection of the most appropriate method according to the designer’s preferences. The model is developed using AHP. Besides, the application