Ocean and Coastal Management 160 (2018) 64–74

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Assessment of ocean wave energy resource potential in Thailand

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ARTICLE INFO

Keywords:
Gulf of Thailand (GOT)
Andaman Sea
Simulated WAves Nearshore (SWAN) model
Ocean wave
Renewable energy

ABSTRACT

Currently, Thailand's energy consumption is increasing rapidly due to its economic expansion. The main source of energy production is still petroleum, accounting for 54% of all energy produced. Considering only electricity, the Electricity Generating Authority of Thailand (EGAT) is able to generate 44% of the demand, which is increasing every year. Ocean waves are an interesting source of alternative energy because ocean wave energy can produce electricity without the limitation of time. The technology that generates power from ocean wave energy can be placed on the surface of the ocean and can be designed to be environmentally friendly to the marine environment. Additionally, ocean wave energy can be predicted and is widely available. Before using ocean wave energy, an assessment of ocean wave energy resources is necessary. Since ocean wave energy converters are currently expensive and have low efficiency due to technical problems, an assessment of ocean wave energy resources is needed for decision making before the development of a project. In Thailand, ocean wave energy can be produced on both coasts because Thailand has the Gulf of Thailand (GOT) to the east and the Andaman Sea situated to the west. The numerical model used in this study is the Simulated WAves Nearshore (SWAN) model. This model, which is suitable for shallow waters, can be used to determine the characteristics of ocean waves, including ocean wave height. The significant wave height is evaluated to assess the natural potential of ocean wave energy in both the GOT and the Andaman Sea using data spanning a 10-year period from 2005 to 2015. Looking at the results for an overall average wave power for all seasons in the Gulf of Thailand, station P5 is the best station to provide wave power. The nearest mainland shore from this station is the nature recreation area in the Kui Buri district, Prachuap Khiri Khan Province. Stations P4 and P11 also provide high wave power. The nearest mainland shore from stations P4 and P11 are the Queen Sirikit Park in Samut Songkhram Province and the Muang-Ngam sub-district in Songkhla Province, respectively. As for the results regarding the Andaman Sea, the highest average significant wave height and wave power are found at station P12. The nearest mainland shore from this station is the nature recreation area in the Mueang Ranong District, Ranong Province.

1. Introduction

The demand for global energy consumption has increased over the last 40 years due to many factors, such as economic expansion, population grown, and an increase in transportation (International Energy Agency, 2014). International Energy Agency (IEA) data from 1990 to 2008 shows that the world population has increased by 27%, and the average energy consumption per person has increased by 10%. In the last 5 years, Thailand's energy consumption has increased due to the expansion of the economy (Energy Policy and Planning Office, 2014). Considering only electricity, its demand has increased every year (Electricity Generating Authority of Thailand, 2014). The main sources used to generate electricity are natural gas (65%), coal (21%), imported electricity (8%), hydropower (3%), oil (1%) and renewable resources (2%).

The Report on Renewable Energy and Climate Change Mitigation provides an assessment and analysis of renewable energy technologies and their current and potential roles in the mitigation of greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2011). Renewable energy technologies that do not emit greenhouse gases are an important and viable part of a near-term strategy for limiting climate change, and they could potentially play a dominant role in global energy supply over longer time scales (National Research Council, 2010; Arent, 2010). Renewable energy is any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. It is obtained from the continuing or repetitive flows of energy occurring in the natural environment. Furthermore, technologies exist that can harness these forms of energy (Intergovernmental Panel on Climate Change, 2011).

An interesting renewable energy is ocean wave energy. Ocean wave energy can be used to generate electricity without the limitation of time. In Thailand, the ocean wave energy potential should be assessed

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https://doi.org/10.1016/j.ocecoaman.2018.04.003
Received 8 May 2017; Received in revised form 7 March 2018; Accepted 8 April 2018
0964-5691/

on both coasts because Thailand has the Gulf of Thailand (GOT) on one side, and the Andaman Sea on the other. The GOT is a shallow ocean with low ocean wave height. The mean depth of the GOT is 58 m, while it is approximately 1000 m in the Andaman Sea. The mean power of ocean wave energy in Thailand is found to be 5–15 kW/m (Intergovernmental Panel on Climate Change, 2011). However, for most countries, resource mapping at the national level has not yet taken place. This is also a significant barrier to the development of ocean wave power generating technologies. A distinct yet related point is the need for industry to improve its understanding of the resource potential and energy capture. Even if the potential is considered low, the development of technologies is required (IRENA, 2014).

There are currently more than 200 different wave energy convertors (WEC) in various stages from many researches. These WEC are developed for the specific properties, for example; different location, ocean depth, shoreline form, wave characteristics, and wave climate, etc. In the report on WECs, Joubert et al. (2013) list, at least, 46 different companies are currently developing wave energy converters with the designs vary somewhat regarding to the style of which the energy is obtained. The efficiency of generators is still a significant area of research and the increase of efficient WEC through a real size-field testing and using are still challenging. Basically, in order to study about ocean wave energy in Thailand, the specific characteristics of WEC should be further studied and should be matched to the wave climate along Thailand's coast, includes Gulf of Thailand and Andaman Sea after knowing the potential of natural ocean wave energy.

As mentioned previously, local assessments of wave ocean energy are important; this study aims to implement a SWAN model for the GOT and Andaman Sea and assess the potential of natural ocean wave energy over the 10-year span from 2005 to 2015. A seasonal wave energy map for the GOT and Andaman Sea are also proposed.

2. Background of wave simulation study

Numerical models are used to study complex processes with the help of the rapid increase in computational techniques and resources. Using numerical models for wave simulation has recently become faster and more affordable (Perkovic, 2006). The WAve Modelling (WAM) is a third generation wind–wave model developed during the 1980s. It solves the energy balance equation (Komen et al., 1984). The model simulates the 2D wave spectral evolution, considering the energy input by wind, energy dissipation by white capping, non-linear wave–wave interactions, and bottom friction. Monbaliu et al. (2000) modified WAM to consider high resolution scales more suitable for shallow water regions. The SWAN model (Booij et al., 1999) is a numerical wave model based on the energy balance equation in the absence of current. It solves the spectral energy balance equation that describes the evolution of the wave spectrum in temporal, geographical and spectral spaces. The Regional Ocean Modeling System (ROMS) is a three-dimensional, free-surface, terrain-following numerical ocean model that solves the Reynolds-averaged Navier-Stokes equations using the hydrostatic and Boussinesq assumption. It was developed and is supported by researchers at Rutgers University and the University of California Los Angeles as well as contributors worldwide. The ROMS model has wetting and drying capabilities, which is of great importance when performing long-term climate simulations (Haidvogel et al., 2008).

Kanbua et al. (2005) modelled the significant wave heights (H_s) in the Gulf of Thailand during typhoon Linda in 1997 using WAM and Neural Network Approach. The results are shown for wave heights below 0.7 m The accuracy of this model decreases for wave height greater than 0.7 m. The significant wave height (H_s) means the average wave height (trough to crest) of the highest one-third of measure waves. In the physical oceanography, H_s is used instead of the wave height in order to use calculation of wave energy. Moreover, the wave energy flux per unit of wave-crest length (kW/m) can be also calculated from H_s. That is the reason why H_s is the important parameter to study the wave energy.

Thanathanphon et al. (2015) studied the application of the SWAN model in the GOT during typhoon Muifa. The results from the SWAN model in this study show good correlation with satellite data; however, the maximum ocean wave height from the SWAN model was lower than the height measured by satellite. Akpinar et al. (2012) evaluated the potential of ocean wave energy resources of the Black Sea. The highest significant waves occurred during December and January, with a maximum wave height at 1.2 m and 7 kW/m of natural ocean wave energy. The lowest significant wave height was in June at 0.5 m high with wave energy of 0.9 kW/m. Bento et al. (2015) used the model to evaluate the wave energy potential in Galway Bay. The numerical models used in the study were WAVEWATCH III (WWIII) for wave generation and deep water propagation and SWAN for wave propagation in intermediate and shallow water. The main wave energy was concentrated during a wave energy period between 4 s and 6 s and significant wave height between 0.5 m and 1.5 m.

The Simulating WAves Nearshore (SWAN) model is used in this study. SWAN is a numerical wave model that can be used to realistically estimate the wave parameters in seas, coastal areas, lakes, and estuaries. The evaluation of wave energy is determined in predefined cells in a grid where every grid contains cells of size Δx, Δy, and over a time interval Δt. This model is based on the wave action balance equation or energy balance that is valid for every frequency and direction component in the spectrum for deep water and in the absence of currents. Equation (1) shows the energy balance equation.

$$\frac{\partial E}{\partial t} + \frac{\partial (c_x E)}{\partial x} + \frac{\partial (c_y E)}{\partial y} = S(\sigma, \theta, x, y, t) \tag{1}$$

where E is action density spectrum, σ is the frequency, θ is the direction, and c_x and c_y are the group velocity in the x and y components, respectively. $S(\sigma, \theta, x, y, t)$ is a source term that represents all effects of generation and dissipation.

In order to apply the energy balance equation to shallow water and surrounding currents, it was converted to the spectral action balance equation for shallow water as shown in Equation (2). The first term represents the rate of change of action in time, and the second and third terms represent the propagation of action in the x and y axis, respectively. The fourth term represents the frequency shift and refraction induced by depth and currents. The last term demonstrates depth-induced and current-induced refraction and propagation in directional space. The term on the right side represents the effects of generation, dissipation, and nonlinear wave-wave interactions. The action density spectrum represents the variance density divided by relative frequency as shown in Equation (3) and the source in terms of energy density is shown in Equation (4).

$$\frac{\partial N}{\partial t} + \frac{\partial (c_x N)}{\partial x} + \frac{\partial (c_y N)}{\partial y} + \frac{\partial (c_\sigma N)}{\partial \sigma} + \frac{\partial (c_\theta N)}{\partial \theta} = \frac{S(\sigma, \theta, x, y, t)}{\sigma} \tag{2}$$

$$N(\sigma, \theta) = \frac{E(\sigma, \theta)}{\sigma} \tag{3}$$

$$\begin{aligned} S(\sigma, \theta) = {} & S_{inp}(\sigma, \theta) + S_{brk}(\sigma, \theta) + S_{frc}(\sigma, \theta) + S_{wcp}(\sigma, \theta) + S_{nl3}(\sigma, \theta) \\ & + S_{nl4}(\sigma, \theta) \end{aligned} \tag{4}$$

where N is the action density spectrum, c_σ is the propagation velocity in the σ-space, and c_θ is the propagation velocity in the θ-space. $S(\sigma, \theta)$ is the source in terms of energy density that includes atmospheric input (S_{inp}), white capping dissipation (S_{wcp}), and nonlinear quadruplet interactions (S_{nl4}). Additional terms for shallow water induced by the finite depth effects play a crucial role and correspond to the phenomena of bottom friction (S_{frc}), depth induced wave breaking (S_{brk}), and triad nonlinear wave-wave interaction (S_{nl3}). The term for atmospheric input (S_{inp}), which represents ocean waves induced by wind, can be described by Equation (5).