Wind resource assessment in the northern gulf of Thailand using atmospheric modeling and climatic database

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Abstract

An assessment of the wind energy potential is an important process in the development of wind power projects. An accurate and precise assessment requires long term wind data, recorded over at least one year by installing a standard met mast, which consumes most of the costs in the early stages of development. Therefore, this research aims to assess the wind resource in the northern part of the Gulf of Thailand, by using the Mesoscale Compressible Community (MC2) atmospheric model and the Modern-Era Retrospective Analysis for Research and Applications (MERRA) climatic database, in order to investigate the mean speed and the technical power potential (TPP). Moreover, the comparison has been made using the Weather Research and Forecasting (WRF) atmospheric modeling along with MERRA climatic database. Results show that the annual mean speed is in the range of 2.3 to 7.5 m/s and the technical power potential, over an area of 1,500 km^2, is in the range of 2,500 MW. The comparison of the results, in terms of the measured/predicted ratio (M/P) and the percent mean relative error (PMRE), is in the range of 0.70 to 0.96, and 4 to 42 %, respectively. Regional outcomes from this study can be applied to develop offshore wind power projects in Thailand.

Keywords: *MC2, offshore wind, MERRA, technical power potential*

1. Introduction

Almost 70% of the fuel needed for power generation in Thailand is natural gas; this affects the energy security of the country. The Government of Thailand enacted the Power Development Plan (PDP 2015) in order to increase the share of renewable energy in power generation. By the end of the PDP2015, the aim of policy makers is to reduce natural gas to a share of 30-40% from the current 64%. The proportion of renewable energy will rise to 15-20% from the current 12%. The new plan foresees a rising share of coal and lignite, up from currently 20% to 20-25% in 2036. An unspecified amount of this capacity is supposed to be delivered as "clean coal" by carbon capture and storage technology. Hydro power should deliver 15-20%, while a share of 0-5% is expected from nuclear power. All shares mentioned refer to total electricity production with focusing on wind power of 3,002 MW in 2036 [1]. At present, the wind power capacity in Thailand is 222.7 MW [2]. All of the wind power generation in Thailand is onshore, which is complicated by land-use issues such as biological, agricultural and inhabited areas. Recently, 7.5 GW offshore wind power has been installed throughout the world. More than 87% of it is installed off Northern Europe, 14% off China east coast and the rest in Japan, Korea and the US. To develop any offshore wind power project, the developer needs to begin with investigation on offshore wind resources [3]. The Gulf of Thailand (GOT) (Figure. 1) is situated from 6º N to 13º30' N latitude and 99ºE to 104º E longitude. It is a shallow, semi-enclosed tropical marine embayment situated in the South China Sea, which is surrounded by the land mass of Malaysia, Thailand, Cambodia and Vietnam. The GOT is relatively shallow with a mean depth of 45 m and a maximum depth of 80 m [4]. Wind power over this area has been estimated using the Mesoscale Compressible Community (MC2) atmospheric model, along with the National Center for Environmental Prediction (NCEP) climatic database [9]. The results show the potential areas of development in the Bay of Bangkok. Although, the latest climatic databases, such as the Modern-Era Retrospective Analysis for Research and Applications (MERRA) climatic database are more accurate in regards to the spatial grid. Therefore, the objective of this paper is to investigate the offshore wind energy potential in the Gulf of Thailand using the MC2 model, along with the MERRA climatic database.

2. Methodology

2.1 Study Area

The study area of this work is selected to investigate the offshore wind energy potential in the Gulf of Thailand, with an emphasis on the northern Gulf of Thailand, as shown as domain 2, the computational domain and global location of Thailand as shown in Fig. 1. The two main resolution domains for computational and geophysical are 3 km and 500 m, respectively.

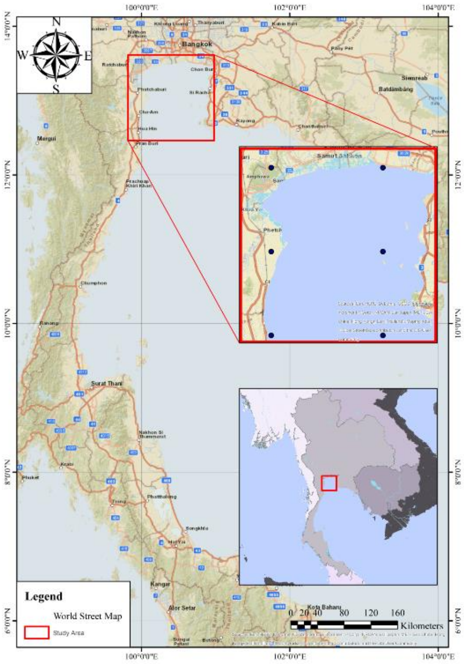

Figure 1. The atmospheric model boundary and domain of study area and a horizontal resolution of 2/3-degree longitude by ½-degree latitude over the Bay of Bangkok and the northern part of the Gulf of Thailand.

2.2 MERRA Database

The Modern-Era Retrospective Analysis for Research and Applications (MERRA) climatic database [5] is a NASA atmospheric reanalysis from satellite data, using the Goddard Earth Observing System Model, Version 5 (GEOS-5) with its Atmospheric Data Assimilation System (ADAS), version 5.2.0. MERRA focuses on historical analyses of the hydrological cycle on a broad range of weather and climate time scales and places the NASA EOS suite of observations in a climate context. MERRA covers the period 1979 to present, continuing as an ongoing climate analysis as resources allow. The GEOS-5 system actively assimilates roughly 2 × 106 observations for each analysis, including about 7.5 × 105 AIRS radiance data. The input stream is roughly twice this volume, but because of the large volume, the data are thinned commensurate with the analysis grid to reduce the computational burden. Data are also rejected from the analysis through quality control procedures designed to detect effects such as the presence of clouds. In order to minimize the spurious periodic perturbations of the analysis, MERRA uses the Incremental Analysis Update (IAU) technique. The analysis is performed at a horizontal resolution of 2/3-degree longitude by ½-degree latitude and at 72 levels, extending to 0.01 hPa. Some products, such as the instantaneous analysis fields, are available on the native three-dimensional grid. Hourly two-dimensional diagnostic fields are also available at the native horizontal resolution. Figure 1 presents the MERRA horizontal resolution of 2/3-degree longitude by ½-degree latitude over the Bay of Bangkok and the northern part of the Gulf of Thailand.

2.2 Mesoscale Compressible Community (MC2) Model

MC2 is a compressible non-hydrostatic limited area model used to develop wind maps (Benoit et al. [6]). The composition of three-dimensional meteorological data is shown in the form of momentum expression displayed in the spherical coordinate system.

$$RT\frac{\partial q}{\partial X} = fV - K\frac{\partial S}{\partial X} \tag{1}$$

$$RT\frac{\partial q}{\partial Y} = fU - K\frac{\partial S}{\partial Y} \tag{2}$$

$$RT\frac{\partial q}{\partial z} = -g \tag{3}$$

where R is the gas constant for dry air (287 J kg^{-1} K^{-1}), T is the air temperature, q is the natural logarithm of the air pressure, f is the Coriolis parameter $f = \Omega \sin\phi$ with Ω being the angular velocity of the Earth's rotation, and ϕ is the latitude, U and V are the component of horizontal wind along X and Y, $K = (U^2 + V^2)/2$ is the kinetic energy, S is the square of the map scale of a map factor m, and g is the effective gravitational acceleration.

In the MC2 model, thermodynamic variations are decomposed into a basic state and perturbation components, $T = T^* + T^{'}$ and $q = q^* + q^{'}$. When this basic state, representing a stationary isothermal atmosphere in hydrostatic equilibrium, $[\partial q^* / \partial z = -g / RT^*]$ is subtracted from equations (1-3):

$$R(T^* + T^{'})\frac{\partial q}{\partial X} = fV - K\frac{\partial S}{\partial X} \tag{4}$$

$$R(T^* + T^{'})\frac{\partial q}{\partial Y} = fU - K\frac{\partial S}{\partial Y} \tag{5}$$

$$R(T^* + T^{'})\frac{\partial q}{\partial z} = g\frac{T^{'}}{T^*} \tag{6}$$

Finally, new variables are defined using the generalized pressure $P = RT^* q^{'}$ and a buoyancy $b = gT'/T^*$, with this change of variables, equations 4-6 become:

$$(1+\frac{b}{g})\frac{\partial P}{\partial X} = fV - K\frac{\partial S}{\partial X} \tag{7}$$

$$(1+\frac{b}{g})\frac{\partial P}{\partial Y} = fV - K\frac{\partial S}{\partial Y} \tag{8}$$

$$(1+\frac{b}{g})\frac{\partial q}{\partial z} = -b \tag{9}$$

2.4 Topographic data

The topographic data used to create the wind resource maps is taken from the Land Development Department, Ministry of Natural Resources and Environment, Royal Thai Government. The corresponding topographic data consists of the Digital Elevation Model (DEM) at a resolution of 30 m, where the ground elevations are recorded in metres relative to the Mean Sea Level (MSL), based on the World Geodetic System (WGS) 1984 reference datum. Before using the topographic data in the modelling, the database are merged into one large raster file with 90 m by 90 m pixels encompassing the entire region of study as shown in Figure 1. The details regarding the land cover and the roughness length [7].

2.5 The technical power potential (TPP)

The technical power potential (TPP) is estimated by identifying a current wind turbine generator (WTG), consisting of a Vestas V112-3.0 MW, with a hub height of 100 m, a rotor diameter of 112 m, a rated wind speed of 12.0 m/s and rated capacity of 3 MW. The area A occupied by a WTG is considered as a square having twelve times the rotor diameter (12D x 12D) and C.F. is a capacity factor of wind turbine generator and the power curve of wind turbine generator is shown in Figure 2. The technical power potential (TPP) is thus given in Chancham et al. [8]

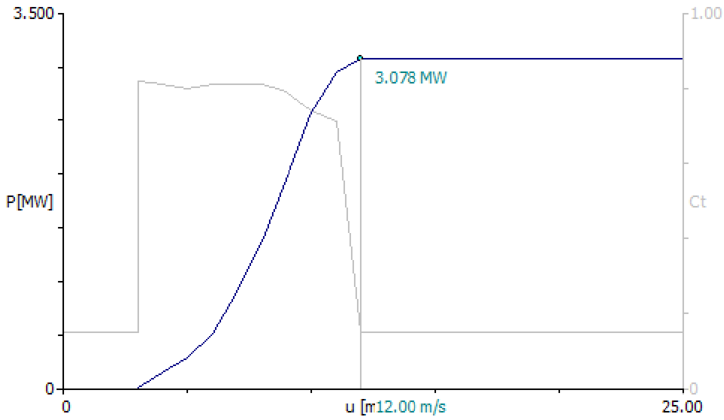

Figure 2. Wind turbine generator power curve that apply to calculate electric and technical power potential.

$$TPP = \frac{A}{12D^2} \times \text{Rated Capacity} \times \text{C.F.} \tag{10}$$

3. Result and discussion

The high resolution wind map, at an elevation of 100 m above sea level (asl), obtained from the modelling is shown in Figure 3. As a result, the mean wind speeds in the Bay of Bangkok vary from 2.3 to 7.5 m/s. It is observed that the computed results based on MC2 along with the MERRA climatic database are not significantly different from the MC2-NCEP presented by Waewsak et al. [4].

An optimal area of development is selected by taking into consideration the marine resources, the navy routes and the submarine cables, which is an area of approximately 20 km radius around the point of latitude 12.12 N and longitude 100.89 E. The technical power potential is in the range of 2,500 MW, which could generate approximately 7 GWh /year.

The wind resource maps were validated using statistical models [8]. This investigation has applied a percent mean relative error and a mean bias to assess the differences between the Weather Research and Forecast based wind data source (WRF-MERRA) and the MC2-MERRAwind data at the same elevation and geological position. The technical power potential area is estimated to be approximately 1,500 km^2, with a potential installed capacity of approximately 2,500 MW in the areas with mean speeds over 7 m/s. The results of wind map validation, shown in terms of measured/predicted (M/P) ratio and the percent mean relative error (PMRE), are found to be in the range of 0.70 to 0.96, and 4 to 42%, respectively. Figure 4 shows a wind speed M/P ratio for the micro-scale (resolution 500 m) wind model, while Figure 5 shows the PMRE for the micro-scale (resolution 500 m) wind model. For its part, Figure 6 presents seasonal time series comparing the mean wind speed at 100 m asl between the WRF-MERRA and the MC2-MERRA databases.

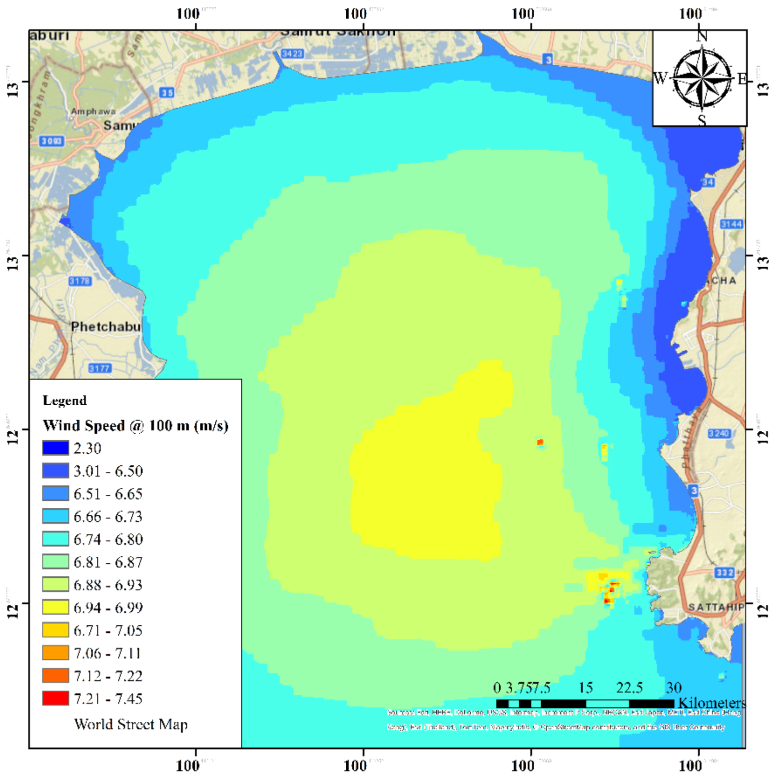

Figure 3. The mean wind speed at 100 m asl in the Bay of Bangkok (resolution 500 m).

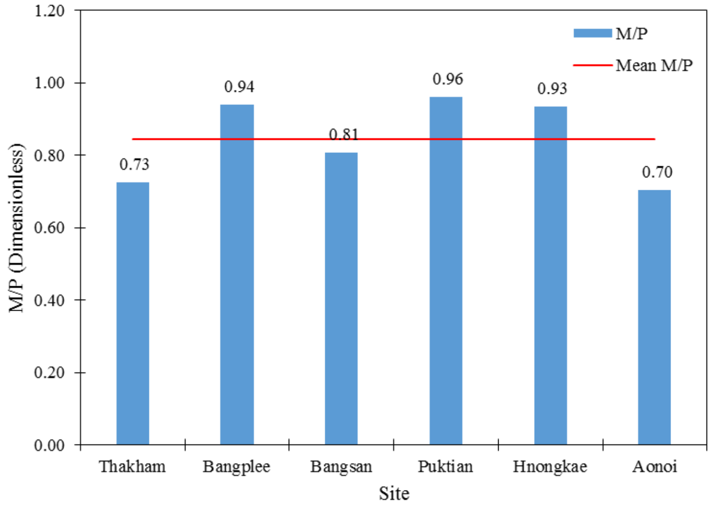

Figure 4. Wind speed M/P ratio for the microscale (resolution 500 m) wind model.

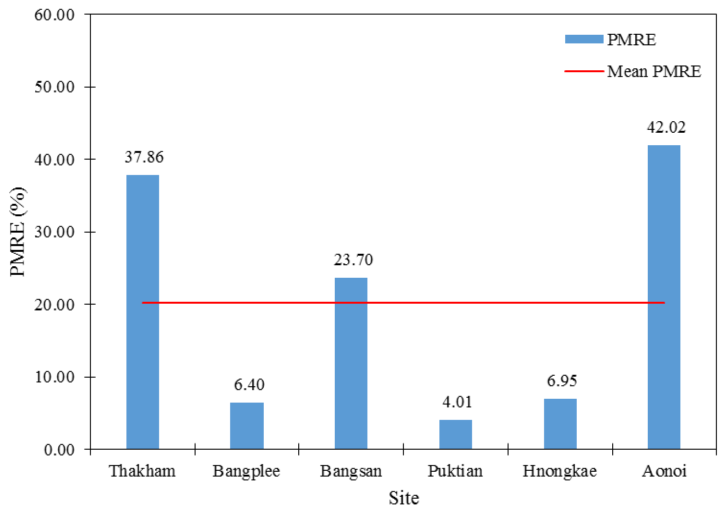

Figure 5. Percent mean relative error (PMRE) for the microscale (resolution 500 m) wind model.

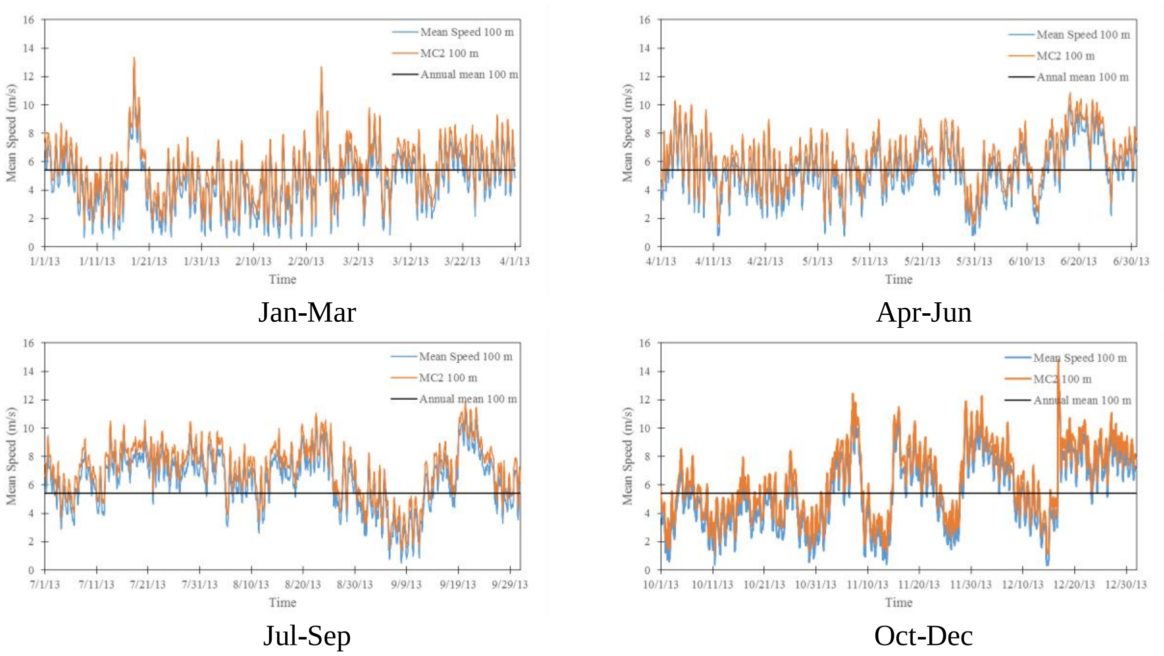

Figure 6. The comparison between MC2-MERRA (orange) wind model and WRF-MERRA (blue) time series.

4. Conclusion

The mean wind speed in the Bay of Bangkok ranges from 2.3 to 7.5 m/s, predicted by applying the MC2 model, along with MERRA climatic database is not significantly different from other models. An optimal area of development is selected by taking into consideration the marine resources, the navy routes and the submarine cables, which is an area of approximately 20 km radius around the point of latitude 12.12 N and longitude 100.89 E. In the validation technique, a percent mean relative error and a mean bias were applied to demonstrate the differences between the WRF-MERRA wind data source and the MC2-MERRA wind data at the same elevation and geological position. The technical power potential area is estimated to be approximately 1,500 km^2, with a potential installed capacity of approximately 2,500 MW in the areas with mean speeds over 7 m/s. The results of wind map validation, shown in terms of measured/predicted (M/P) ratio and the percent mean relative error

(PMRE), are found to be in the range of 0.70 to 0.96, and 4 to 42%, respectively. On the basis of this work, wind developers should install offshore wind measurement equipment, over a period of not less than one year to confirm the precision and feasibility of offshore wind projects.

Acknowledgements

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