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AN EMPIRICAL MODEL FOR FORECASTING ELECTRIC GENERATION FOR NEARSHORE ENERGY POTENTIAL IN THAILAND

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This paper presents electrical energy forecasting from near shore wave potential in the Gulf of Thailand using an empirical model. An electric generator was installed on the near shore to perform measurements and create an empirical model for predicting electric generation. In order to forecast the capacity of the electric generation from sea waves with sufficient electricity consumption, the household data in the Gulf of Thailand and the Andaman Sea were collected from the year 2012 – 2019 to forecast the increasing rate of the number of households in the five years period (2021-2025). Cost and payback period were analyzed in each location in order to invest the renewable energy generation.

Keywords: sea waves, electrical energy forecasting, Gulf of Thailand, Andaman Sea, empirical model, electricity consumption

1 INTRODUCTION

Currently, the issue of global warming is getting more attention. Climate change affects the environment, which is due to human activities, both industrial activities and consumer behaviors. These activities have increased the amount of greenhouse gases in the atmosphere, causing a more severe greenhouse effect than would be natural. Global warming will have increased the global surface temperature, which is a risk of severe weather conditions such as heat waves, droughts and floods. The use of energy in the industrial sector and the household energy consumption is one of the drivers of global climate change. Therefore, the clean energy should be encouraged by using solar, wind, and wave energy. The renewable energy is clean energy, the production process does not emit carbon dioxide (CO_2), or other greenhouse gas emissions. Therefore, the renewable energy has an opportunity to develop and reduce the dependence on fossil fuels. The waves energy in the Gulf of Thailand and the Andaman Sea have enough potential to generate electricity in the future. The Ministry of Energy of the Kingdom of Thailand is responsible for the planning of electricity production. The power development plan is a roadmap for electric power generation, distribution, and consumption. The power development plan emphasizes the sufficient electric power source in which the use of electricity increases according to the rate of economic growth. Thailand has conducted a study of sea wave energy in the Gulf of Thailand and the Andaman Sea. According to the Alternative Energy Development Plan (AEDP) 2012-2021, at least 10 GWh of new energy will be promoted. Many researchers studied the development of electric power generation from waves. The wave power sources in the Gulf of Thailand are around Samui, Phangan, and Taen islands, while the Andaman Sea is around Phuket province and nearby as detailed in the next section. Encouraging the use of renewable energy will reduce the amount of carbon dioxide emissions from electric power generation. It is estimated that Thailand will emit carbon dioxide in 2036 in the amount of 0.39 $kgCO_2/kWh$ or 104,075 tons [1]. The benefit of using renewable energy will help to decrease the use of fossil fuels and oil. In the environment, it will reduce carbon dioxide emissions which would alleviate the global warming problem. From the policies, Thailand has explored and developed the technology for generating electricity from sea waves. Thailand has two coastlines, the Gulf of Thailand and the Andaman Sea. The Gulf of Thailand has an average depth of 45 meters and the deepest of 80 meters [2]. The average depth of the Andaman Sea is about 1,096 m while the deepest part in the central channel is about 4,198 m. The Simulating Waves Nearshore (SWAN) model was used to calculate the significant wave heights, which were validated with the measurement data of the Jason-2 satellite. The coastal area of Phuket and PhangNga provinces are suitable locations for studying wave energy converters because they have high significant wave heights [3]. The potential of wave energy and power generation are still studied and developed in the East China Sea, the South China Sea, the Black Sea, the Red Sea, and the Indian Ocean. In the South China Sea, the study found a potential mean wave power of 6.61 kW/m. A single wave energy converter Pelamis P2 can produce an average electricity output of 91.37 kW/m including, loss and machine efficiencies, whereas a wave farm can generate an average output of 62 GWh/year [4]. The study about Floating Sea Energy Conversion Device (FOECD) in the East China Sea and the South China Sea were conducted to improve the safety of the wave energy conversion devices.

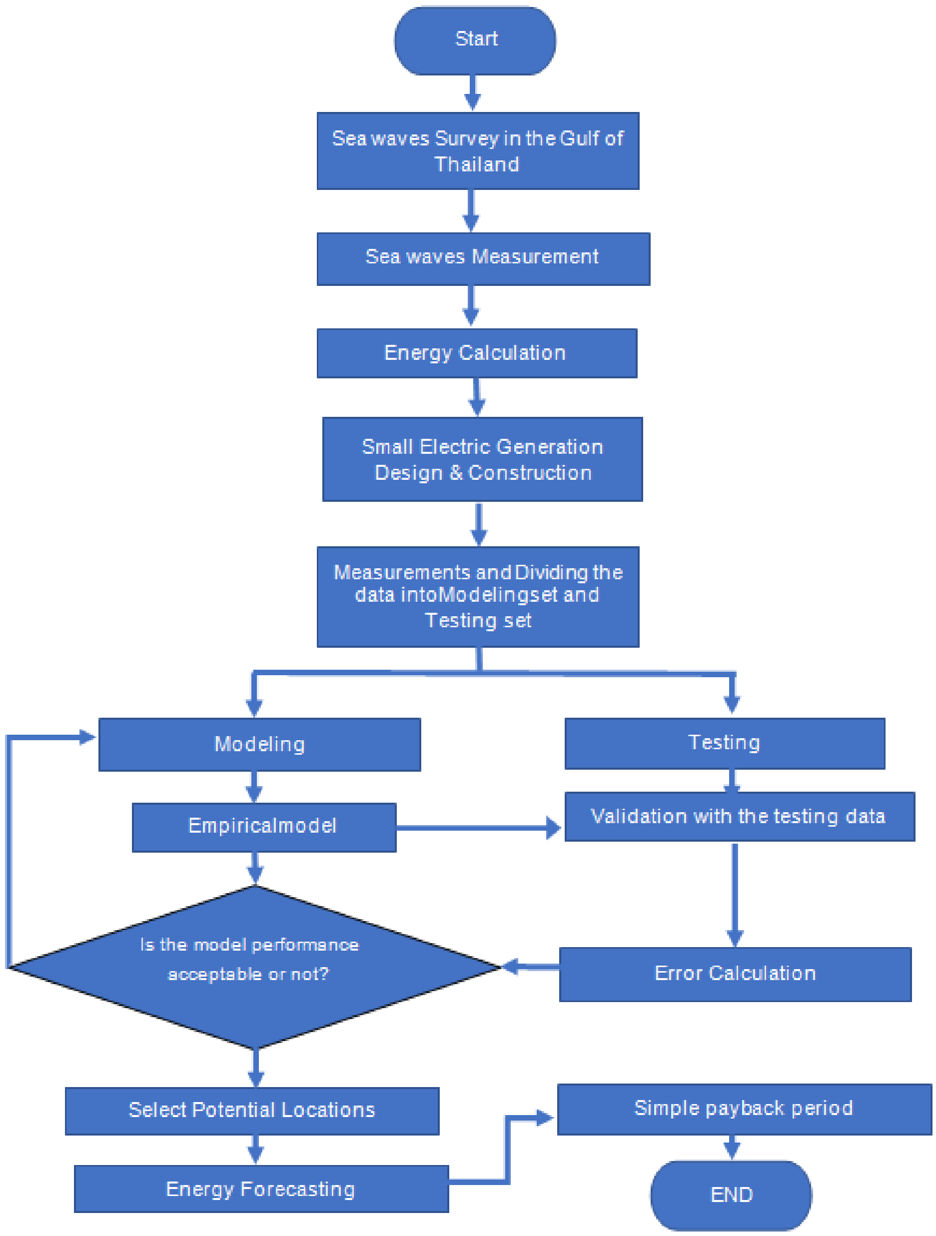


Fig.1. Flowchart of research methodology

The harvested power only rises from 3.5 kW to 3.7 kW. It reveals that the shape and scale of the circular cone for the buoy have no apparent influence on the power harvesting capabilities [5]. In the Black Sea, the evaluation of the energy characteristics can be carried out both according to the calculated and experimental data. The article provides a method for calculating the area, volume, mass, phase velocity, and kinetic energy of sea waves based on the theory that the waveform is an inverted shortened cycloid [6]. In the Red Sea, the study aims to find the best location for installing wave energy converters (WEC) in the NEOM area, located in the Red Sea northern region, and to determine the most suitable converter system for harvesting wave energy using available data provided by KAUST [7]. In the Indian Ocean, the potential of wave energy has been studied around the island of Sri Lanka. In the above area, the mean annual energy potential is estimated to be 10 kW/m at 25 m depth, whereas the maximum annual potential energy is estimated to be 36 kW/m. During the South-West monsoon where the wave heights are presented, the mean energy potential is estimated to be 15 kW/m [8]. In the Mediterranean Sea, the researchers have been to identify long-term Mediterranean Sea Offshore Wind (OW) classification [9]. The case of waves energy, they studied the optimization of geometry, tether angles, and power take-off (PTO) settings of a wave energy converter (WEC) at a site in the west of Sicily, Italy. The Moth–Flame Optimiser (MFO) outperformed other optimization methods [10]. Furthermore, there is a comparative study of oscillating surge wave energy converter performance on the Caspian Sea's southern coasts. The study uses the oscillating surge wave energy converters flap geometric dimensions as the data to simulate in the MATLAB software. The results found that the Nowshahr port has more potential than the Anzali and Amirabad ports, under the condition's absorbed power of 16.7 kW/m (Capture factor = 63%) at these sites [11]. The methods in references above use the different models and study at the different environment sites. This paper proposes electrical energy forecasting from nearshore in the Gulf of Thailand and the Andaman Sea. The next section follows the research methodology as shown in Fig. 1.

Table 1. List of abbreviations

Parameter	Symbol
Potential Energy	*P.E.*
Kinetic Energy	*K.E.*
Wave mass	*m*
The density of seawater	ρ
wave width	*w*
Gravity constant	*g*
Wave number	*k*
Wavelength	λ
Wave energy period	T_e
Wave frequency	ω
Wave height	H_w
Wave amplitude	*a*
Zero-crossing period	T_z
Significant wave height	H_s

2 SEA WAVES ENERGY

Sea waves are a moving or swell of water occurring close to the surface of the sea. These waves are created by direct local action on the sea. The characterized waves have oscillating, rising, and falling movements. The simple shape of the sea wave is shown in Fig. 2. The peak of the wave is the crest, and the bottom of the wave is the trough. The wave height (H_w) is the difference between the trough and the crest, while the range between two consecutive troughs or crests shall be the sea wave wavelength (λ). The potential energy (P.E.) of the wave is computed in x-y coordinate as the equation (1)

$$P.E. = mg\frac{y(x,t)}{2} \qquad (1)$$

where, m is the wave mass (kg), The sinusoidal wave equation (m) is

$$y = y(x,t) = a\sin(kx - \omega t) \qquad (2)$$

and

$$\Delta(P.E) = \lim_{\Delta x \to 0}(w\rho g y \Delta x)\frac{y}{2} \qquad (3)$$

where ρ is the density of the sea water (kg/m^3), and w is the wave width (assume that the width is equal to the width of power receiver contacts) (m). The wave mass is

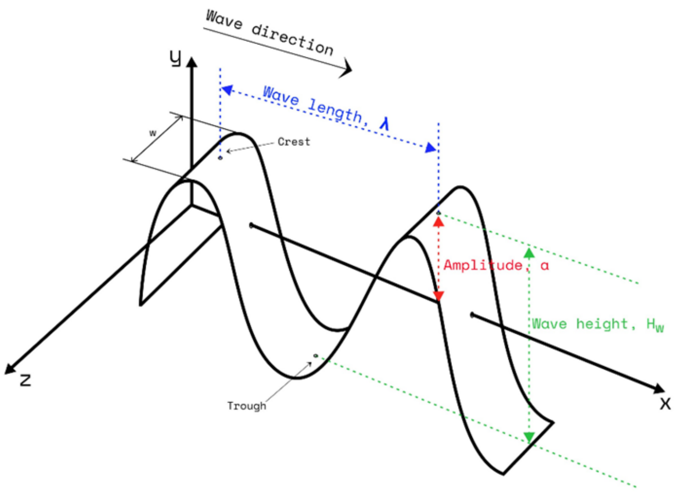


Fig. 2. Sinusoidal wave

$$\Delta m = \rho(wy\Delta x)$$

and

$$d(P.E.) = w\rho g y dx\frac{y}{2} = w\rho g\frac{y^2}{2}dx (3)$$

Therefore, the potential energy in a period can be written in the equation (4). Let the wave be written as a function of x which is independent of time. Then, $y(x,t) = y(x)$, the potential energy is determined:

$$d(P.E.) = \frac{1}{2}w\rho g a^2 sin^2(kx-\omega t)dx$$

$$\int_0^\lambda d(P.E.) = \int_0^\lambda \frac{1}{2}w\rho g a^2 sin^2(kx-\omega t)dx$$

$$P.E. = \int_0^\lambda \frac{1}{2}w\rho g a^2 sin^2(kx-\omega t)dx$$

$$= \frac{1}{2}w\rho g a^2 [\frac{1}{2}x - \frac{1}{4}sin2(kx-\omega t)]_0^\lambda$$

$$= \frac{1}{2}w\rho g a^2 [\frac{\lambda}{2} - \frac{1}{4}sin2(k\lambda-\omega t) - 0]$$

$$= \frac{1}{4}w\rho g a^2 \lambda \qquad (4)$$

where, $a = \frac{H_W}{2}$ is the wave amplitude (m) and H_w is the wave height (m), $k = \frac{2\pi}{\lambda}$is the wave number, λ is the wavelength (m), $\omega = \frac{2\pi}{T}$ is the wave frequency (rad/s), and T is the period (s). However, the kinetic energy in a period is equal to the total potential energy. Therefore, the kinetic energy will be equal to the potential energy in the equation (5):

$$P.E. = \frac{1}{4}w\rho g a^2 \lambda \qquad (5)$$

Finally, the total energy in a period is determined

$$E_w = P.E. + K.E. = \frac{1}{2}w\rho g a^2 \lambda \qquad (6)$$

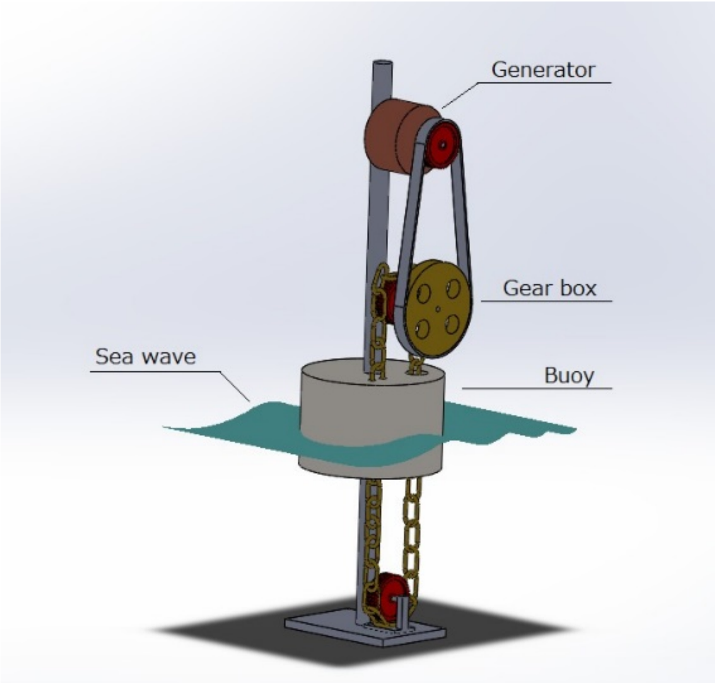


Fig. 3. Electric generation system from waves energy

The wave energy per unit area can be assigned as:

$$\bar{E} = \frac{E_W}{W\lambda} = \frac{1}{2}\rho g a^2 \qquad (7)$$

To substitute the height of sea wave into amplitude of wave a, the equation becomes

$$\bar{E} = \frac{1}{8}\rho g H_w^2 \qquad (8)$$

The equation (8) is the same as the wave energy in equation (2.2) in [12]. Multiply the equation (8) by the wave group velocity $c_g = \frac{gT_e}{4\pi}$ (m/s) [3-4], the power per unit length would be as follows:

$$P = c_g \bar{E} \qquad (9)$$

whereT_e is the wave energy period (s). The power (P) transmitted by a regular per unit crest is obtained as:

$$P = \frac{1}{32\pi}\rho g^2 H_w^2 T_e \text{(W/m)} \qquad (10)$$

And[4]

$$P = \frac{1}{64\pi}\rho g^2 {H_s}^2 T_e \qquad (11)$$

where$H_s = \frac{2H_w}{\sqrt{2}}$

If sea water has a density of 1025 kg/m^3, the wave energy flux per unit of wave-crest length (kW/m) $\bar{P}$ for shallow water can be shown as Equation (12):

$$\bar{P} \approx 0.55 H_s^2 T_z \qquad (12)$$

where T_e=1.12T_z, T_z is zero-crossing. Equation (12) derive from Equation (10) which corresponding to the equation (7) in [4].

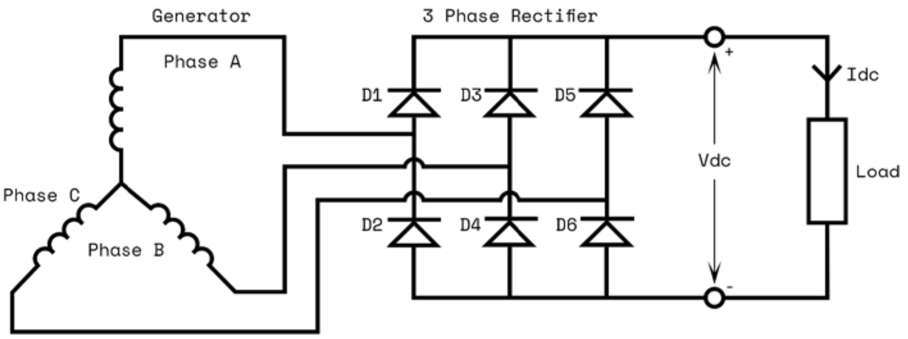


Fig. 4. Generator and rectifier circuits

3 ELECTRIC GENERATION

The wave energy conversions for nearshore were installed to save cost and for the safety [13]. The small linear permanent magnetic generators (LPM) were popularly used for converting the wave energy to electrical energy. The Inertial Sea Wave Energy Converter (ISWEC) based on a gyroscope produced maximum electric power [14]. The system consisted of two linear tubular permanent-magnet generators of 3 kW. The linear generator uses a direct drive for sea wave energy converter (DD-WEC). It has been designed and installed in the China's Yellow Sea [15]. The linear tubular generator provided the maximum power of 2 kW. Additionally, the LPM generator was designed and constructed with a power of 3.5 KW [16]. The system mainly consisted of LPM generator and buoy components. The planar double-sided LPM structure provided power of about 300 W [17]. In order to increase the output power, the array of floating cylinders [18] and buoy shape [19] were proposed. However, the above linear tubular permanent-

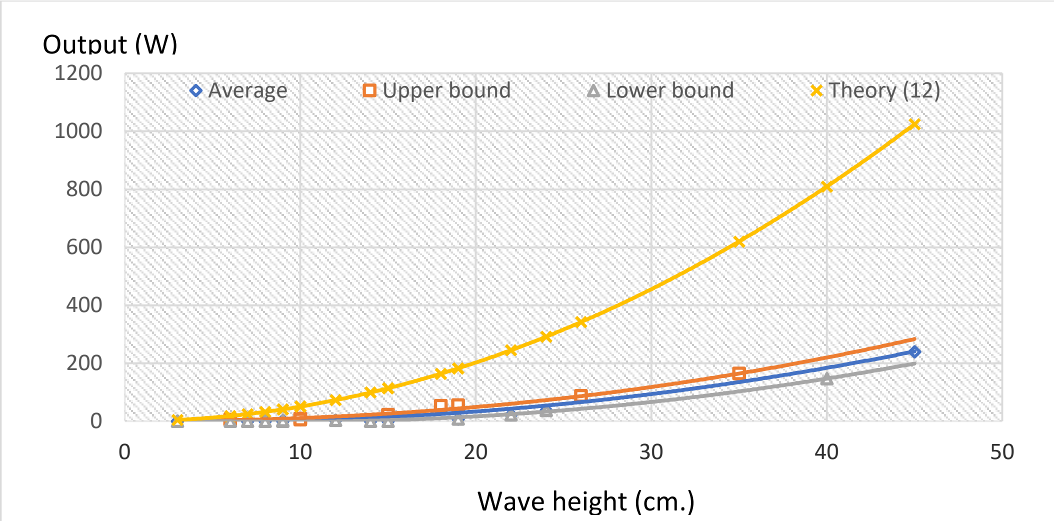


Fig. 5. Output power of the generator

magnet generators may have problems about the friction of tubular components and the cost of construction. To overcome these problems, this paper proposed a rotary permanent-magnet generator with a cylinder buoy and predicted the electric generating from the wave energy. A generator prototype was constructed and installed for collecting the data. The main components of this electric generator consist of a buoy with a 1.2 m diameter, a 400 W permanent magnetic generator from a washing machine, and a gearbox with a ratio of 7: 1 as shown in Fig. 3 [20]. When the sea wave pushes up a floating buoy, the transmission chain of gear will drive the generator to produce electric power. The electric power depends on the wave height and period of the wave. The generation system was installed on the base station at the nearshore of the Sirindhorn International Environmental Park, Cha-am, Phetchaburi province in the South of Thailand. The researchers performed measurements of the wave height and electric power by using a video camera and power meter. The generator consists of three phases winding with four wires as shown in Fig. 4. In order to provide the maximum power output, loads were connected with a delta connection.

Fig. 6. Locations of energy forecasting

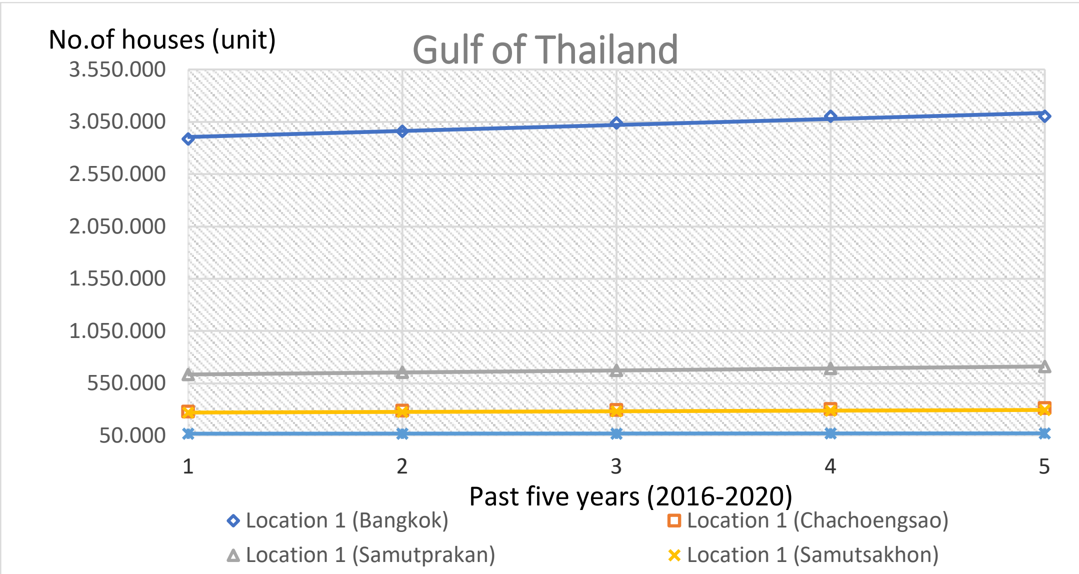
The equation for the relationship between wave height and electric power is expressed as:

$$\bar{P} = 1589.5 H_w^{2.16} \qquad (13)$$

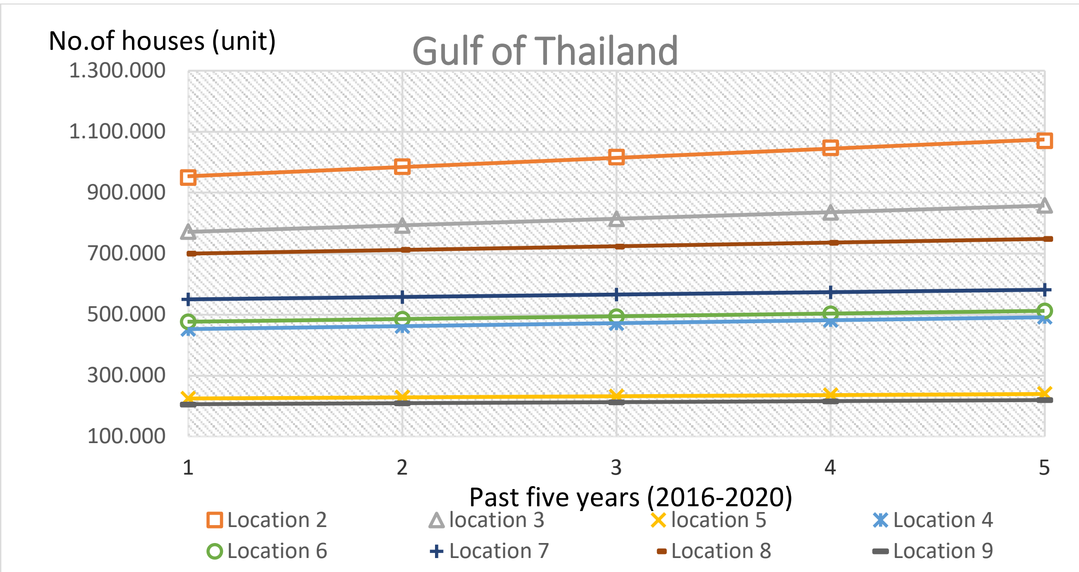
where *P* is the electric output power produced (W) and H_w is wave height (m). The maximum power occurred at a wave height of 45 cm as shown in Fig. 5. While some incident sea waves were not equal to the natural frequency of the buoy and made small output powers as shown on the lower boundary of the graph. The upper boundary represents the maximum power at the resonance between the incident wave and the buoy. However, the empirical equation (13) provides about 24% of the power theory in equation (12) with a wave energy period of 4.6 s. The equation (13) is used to predict the energy generation for real environments.

4 FORECASTING LOCATIONS

In order to forecast the electrical energy, 14 locations were selected from both Gulf of Thailand and Andaman Sea as shown in Fig. 6. There are a number of house growth near the forecasting locations in the past five years of the Gulf of Thailand and the Andaman Sea as shown in Fig. 7 and 8, respectively. The forecasting locations in the Gulf of Thailand consist of 4 provinces around Bangkok that contact the sea namely Chachoengsao, Samutprakan, Samutsakhon and Samutsongkhram together with 4 provinces in the East namely Chonburi, Rayong, Chanthaburi and Trad. In case of the South of Thailand, it consists of 8 provinces namely Phetchburi, Prachuapkhirikhan, Chumphonsuratthani, nakhonsrithammarat, Songkhla, Pattani and Narathiwat. For the Andaman Sea, the forecasting locations are in 6 provinces namely Ranong, Phangnga, Phuket, Krabi, Trang and Satun. The normal household of fisherman family would be used for forecasting from past five years to future five years [21]. The maximum house growth is in location 1. This is because of the influence in Bangkok growth. However, the minimum growth is in Samutsongkham as shown in Fig. 7 a). While the minimum one is in location 10 (Ranong) as shown Fig. 8. In this research, the researchers used the average energy consumption per month per household of about 624 kWh [22]. The total energy consumption of the household in each location is obtained as shown in Table 2. The maximum energy consumption in location 1 (Bangkok Metropolitan Region) is about 2,762.17x106 kWh/month while the minimum one in location is about 57.88 x106 kWh/month (Table 2).



a) Location 1



b) Locations 2-9

Fig. 7. Number of household growth at the locations in Gulf of Thailand

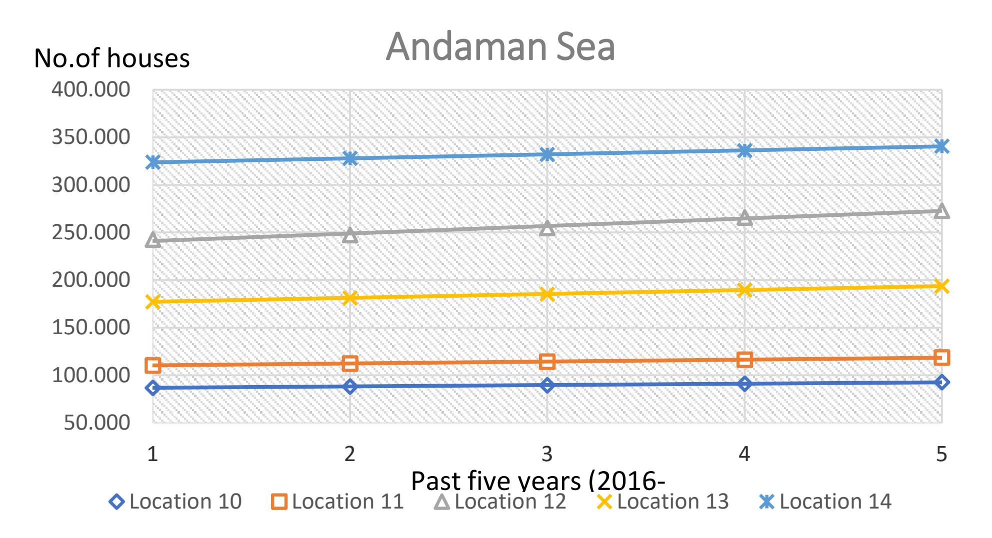


Fig. 8. Number of household growth at the locations in Andaman Sea

Table 2. Total energy consumption of households in each location

Position	Province	2016	2017	2018	2019	2020	Energy Consumption kWh/5 years
1	Bangkok	1802005	1847098	1898021	1936946	1975871	
	Chachoengsao	175863.3	180602.9	185589.6	190432.1	195715.3	
	Samutprakan	395740.1	409192.4	421519.4	433093.1	444251.1	
	Samutsakhon	169258.2	173622.7	177158.3	181497.2	185254.4	
	Samutsongkhram	42580.59	43357.62	43936.18	44503.5	45393.5	
	(Total)	2585448	2653874	2726224	2786472	2846485	13598502.56
2	Chonburi	592807.3	615050.9	634609	653748.8	667938.8	3164154.84
3	Rayong	276396.5	285742.7	295581.4	305579.8	316279.7	
	Chanthaburi	141620.9	144226	146825.5	149279.5	152114.9	
	Trad	63881.8	64837.95	65676.77	66584.24	67573.47	
	(Total)	481899.3	494806.7	508083.6	521443.5	535968	2542201.16
4	Phetchburi	127882.8	130385.5	132955	135166.3	137532.3	
	Prachuapkhirikhan	154893.5	158304.9	161573.4	165534.7	169692	
	(Total)	282776.3	288690.5	294528.5	300701	307224.3	1473920.54
5	Chumphon	140447.6	142781.8	144956.2	147389.7	149943.6	725518.90
6	Suratthani	297580.4	302700.1	308088.1	313965.4	319777.9	1542111.89
7	Nakhonsrithammarat	343193	348078.6	352944.9	357754.9	363205.4	1765176.75
8	Songkhla	323471.4	329227	333910.4	339445.8	345511	
	Pattani	113280.9	115556.4	117514.9	119462.2	121843.2	
	(Total)	436752.3	444783.5	451425.4	458907.9	467354.2	2259223.28
9	Narathiwat	128281	130540.3	132858.3	134640.2	136933.8	663253.57
10	Ranong	54254.13	55061.11	55911.17	56869.19	57880.26	279975.86
11	Phangnga	68856.04	70071.2	71391.84	72700.62	74026.25	357045.95
12	Phuket	151500.1	154451.6	159118.1	166074	170333	801476.80
13	Krabi	110589.1	113231.6	115555.8	118277	120892.7	578546.13
14	Trang	139640.6	141354.4	142999.6	144748.4	146582.7	
	Satun	62536.2	63439.3	64296.22	65083.86	66096.18	
	(Total)	202176.8	204793.7	207295.8	209832.3	212678.9	1036777.53
	(Grand Total)						19436704.53

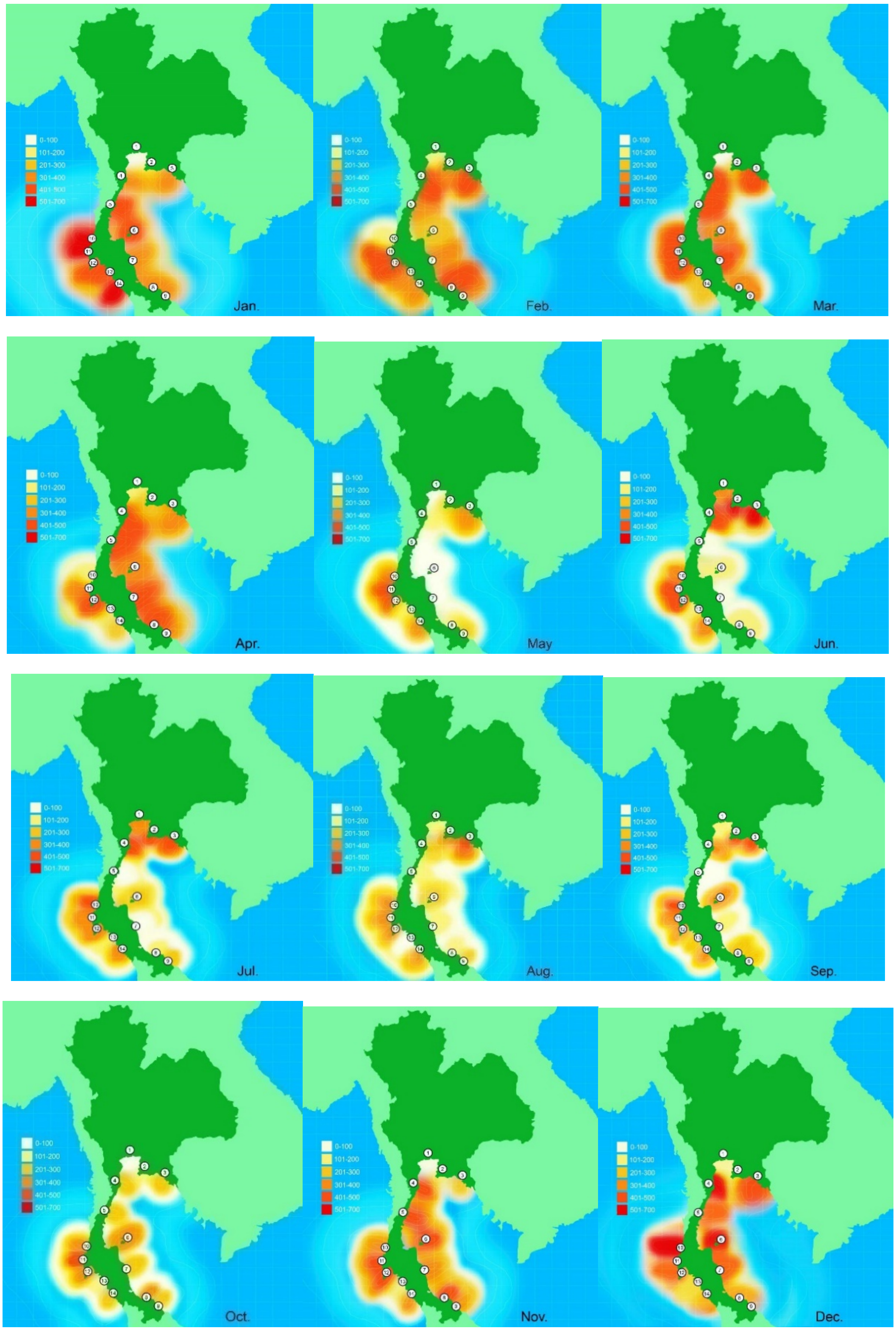


Fig.9.Forecasting of output powers in 12 months

Table 3. Energy forecasting in each location and breakeven

No.	Province	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	kWh/Y	Breakeven
1	Bangkok	37	146	75	128	95	397	335	188	172	34	6	130	1743	16,2
2	Chonburi	133	319	293	276	227	505	473	384	452	123	119	247	3551	8,0
3	Rayong	367	408	402	368	332	518	491	477	495	211	229	500	4798	5,9
4	Phetchburi	380	413	434	409	184	459	402	262	304	297	402	517	4463	6,3
5	Chumphon	425	367	412	424	48	81	44	125	79	255	407	467	3134	9,0
6	Suratthani	453	242	396	306	83	180	233	213	331	320	441	501	3699	7,6
7	Nakhonsrithammarat	391	400	416	428	74	39	88	116	130	248	388	424	3142	9,0
8	Songkhla and Pattani	350	404	398	425	181	109	134	184	225	327	403	369	3509	8,0
9	Narathiwat	305	341	349	380	215	155	201	214	234	294	374	316	3378	8,4
10	Ranong	504	184	408	191	397	419	430	397	437	316	323	668	4674	6,0
11	Phang nga	511	436	467	388	426	359	379	375	373	401	406	499	5020	5,6
12	Phuket	482	451	455	426	432	355	377	376	369	399	400	492	5014	5,6
13	Krabi	437	372	295	104	197	211	155	89	207	159	132	284	2642	10,7
14	Trang and Satun	544	390	275	212	380	368	382	376	373	274	338	390	4302	6,6

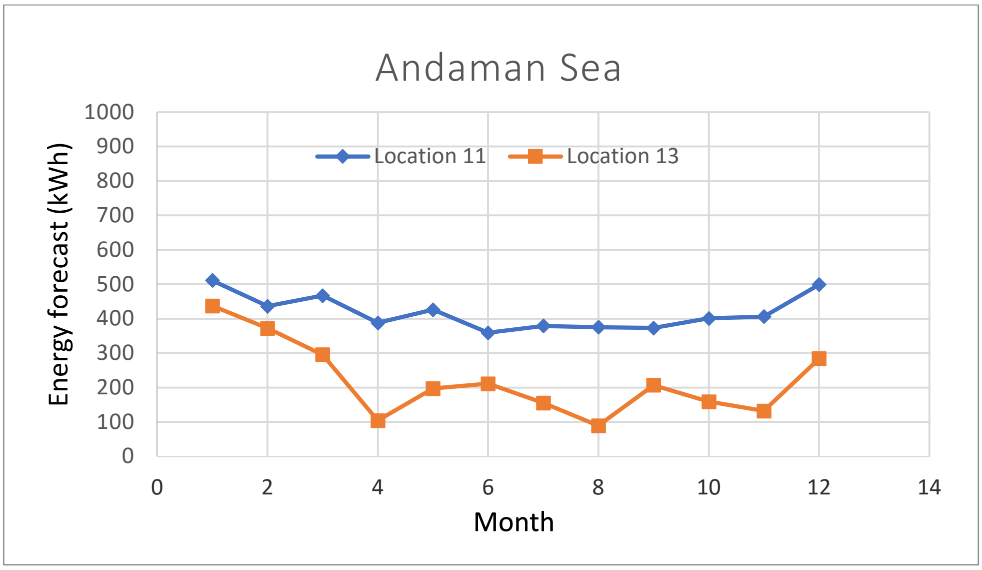


Fig. 10. Maximum and minimum energy forecast in the Andaman Sea

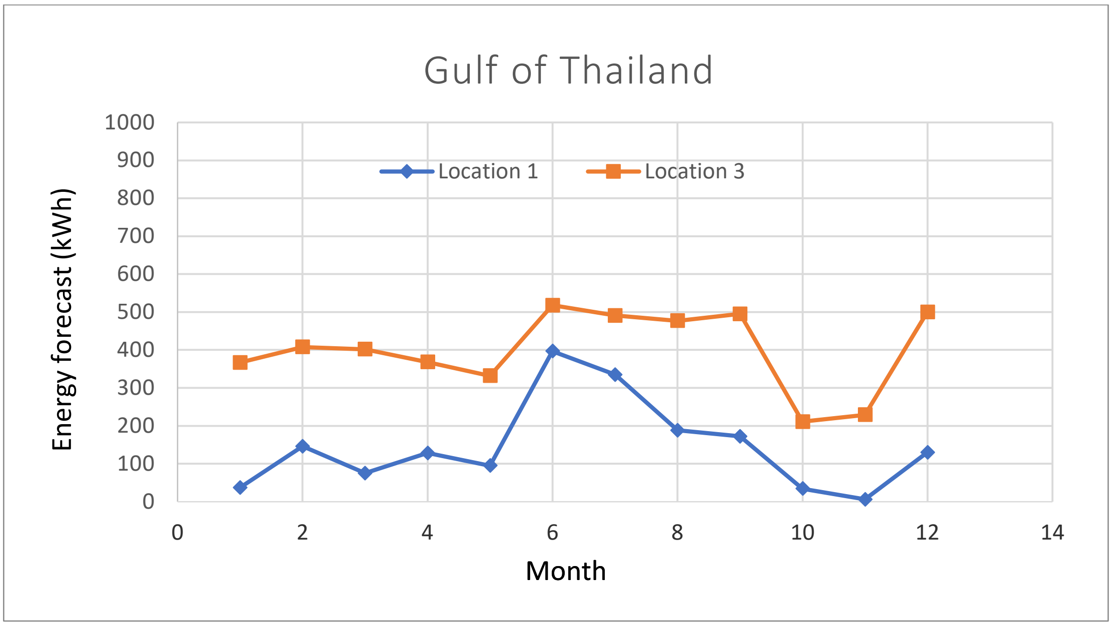


Fig. 11. Maximum and minimum energy forecast in Gulf of Thailand

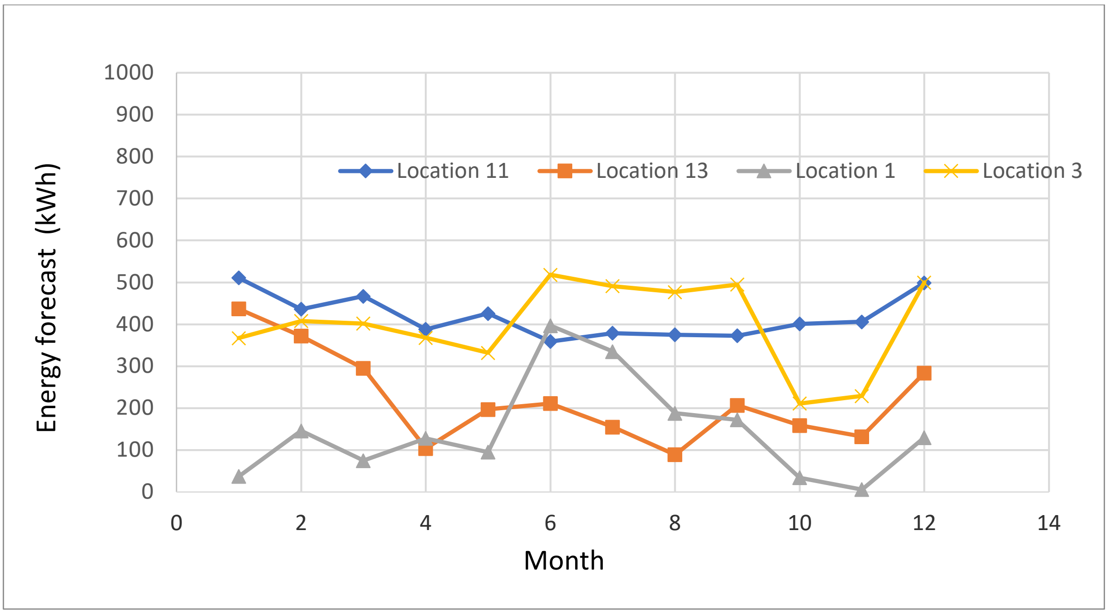
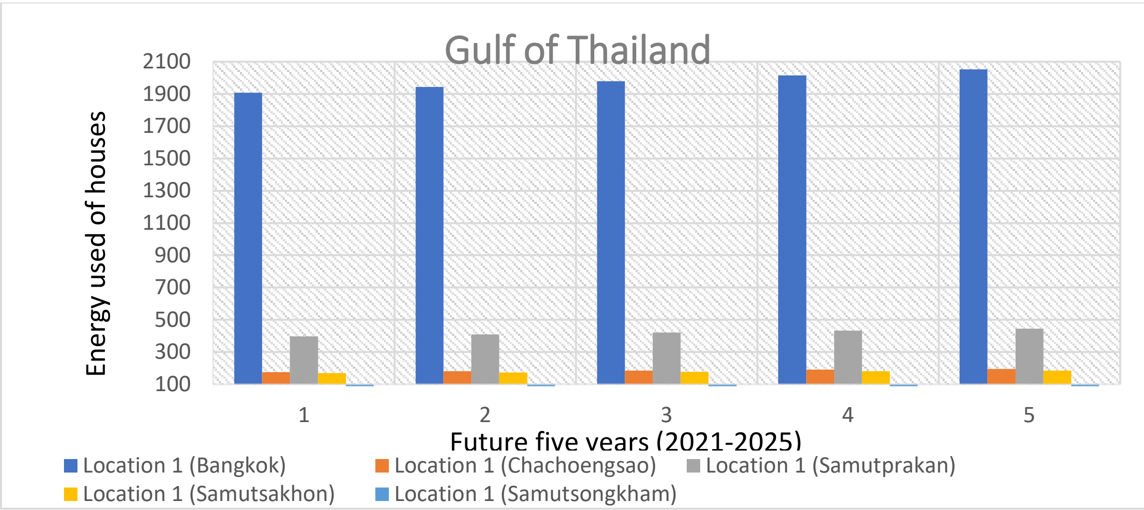
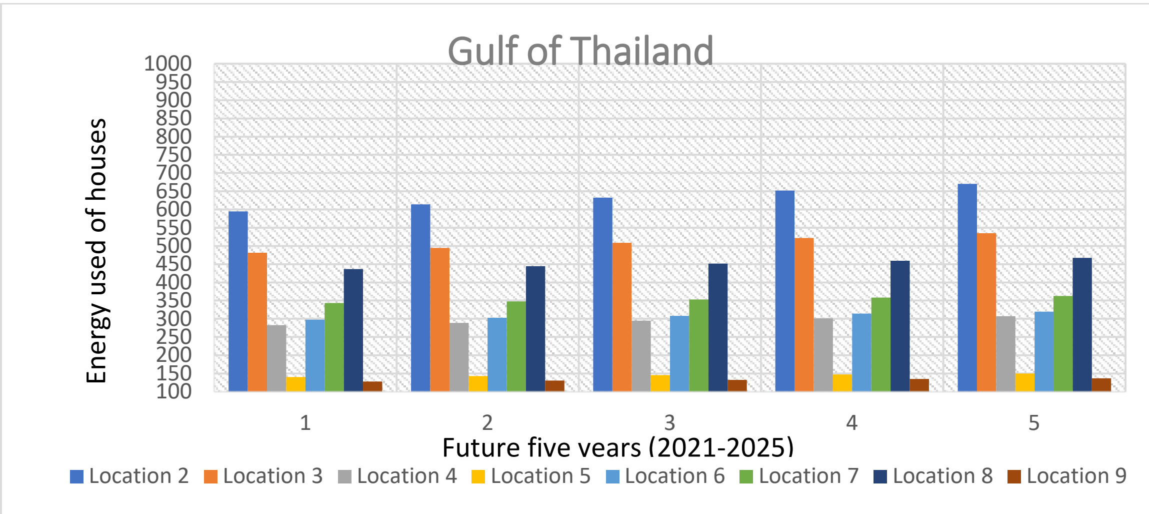


Fig. 12. Comparison of Energy forecast in two Sea sides



a) Location 1



b) Locations 2-9

Fig.13.Five years demand forecasting in the Gulf of Thailand for the future

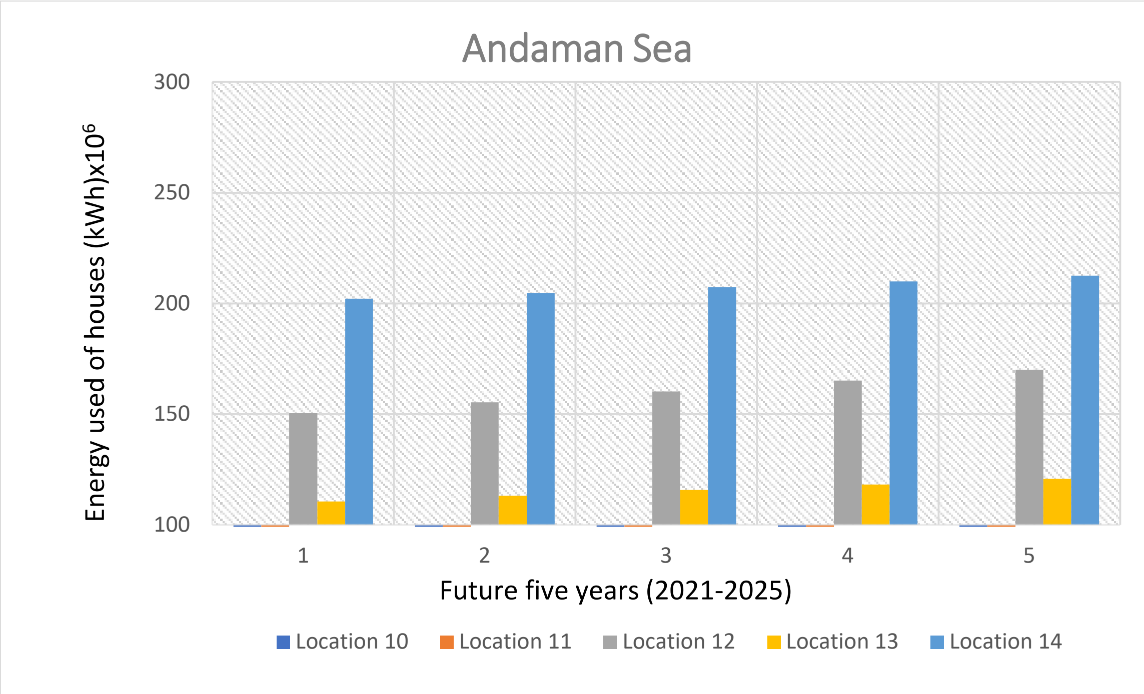


Fig. 14. Demand forecasting in future five years for the Andaman Sea

5 RESULTS

In order to determine the wave power potential, the measured wave data at 3-hour time step in a month is generally analyzed [23]. The researchers used wave height input H_w from Thai Meteorological Department [24] that provided daily wave analysis and 24-hour wave forecasting charts to the general public. The domain covers from longitudes 95E to 105E and from latitudes 5N to 15N, which encompasses the Gulf of Thailand and the Andaman Sea. The wave analysis and forecast are mainly obtained from significant wave and wave spectral methods in the computation. The forecasting results of all locations and months are shown in Fig. 9 and Table 3. In the Fig., the color scale represents the amount of the electric energy in kWh. It was found that the energy forecasting provides a maximum value of 668 kWh/month at location 10 (Ranong) in the Andaman Sea in December while a minimum value of 6 unit/month at location 1 (Bangkok Metropolitan Region) in the Gulf of Thailand in November (Table 3). In the Andaman Sea, the overall energy forecasting provides the maximum value of 5,020 kWh/year at location 11 (Phang-nga) compared with the minimum value of 2,642 kWh/year at location 13 (Krabi) as shown in Fig. 10. In the Gulf of Thailand, the minimum value of 1,743 kWh/year at location 1 compared with the maximum energy occurred with 4,798 kWh/year at location 3 (Rayong) as shown in Fig. 11. Comparison between the energy generating in the Gulf of Thailand and the Andaman Sea, location 3 (Rayong) provides maximum overall energy almost equal to that of location 11 (Phangnga) as shown in Table 3. Both location 1 and location 11 (Krabi) provide the lowest overall energy as shown in Table 3. The locations in the Andaman Sea provide the average energy of 4,330 kWh/y per location while the locations in the Gulf of Thailand provide the average energy of 3,491 kWh/y per location. Note that, the maximum energy in the upper Gulf of Thailand occurred between June and July due to the southwest monsoon winds while the maximum energy in the lower Gulf of Thailand occurred from November to April due to northeast monsoon winds. The maximum energy in the Andaman Sea occurred between December and January because of a period of inclement weather with thunderstorms. In term of the breakeven point, the cost of the generation system was investigated. The cost consists of hardware and maintenance service while the price of electric energy depends on electric charge of the government service organization. The breakeven point of location 11 and 12 in the Andaman Sea are 5.6 years, respectively. The breakeven point of location 3 in the Gulf of Thailand is 5.9 years as shown in Table 3. These locations above have the higher electricity energy than the other locations. If the breakeven point time is less than 5 years, then it will be suitable to invest. Bangkok and Metropolitan Region have the highest electricity demand 5 years in the future as shown in Fig. 13a. Additionally, the other locations (2-9) in the Gulf of Thailand provide large overall demands compared with the locations in the Andaman Sea as shown in Fig. 13 b) and Fig. 14. The small electricity demands are about 100 x106 kWh in the location of 5, 9, and 13. This demand information is used for green energy investments.

6 CONCLUSION

The electrical energy forecasting from sea waves potential in Thailand is proposed. An electric generator was installed in order to perform measurements of the wave height and electrical power generation. The measurement data were used to create an empirical model in order to forecast the capacity of the electricity generation from sea waves. The number of households nearshores collected from the last five years was used to forecast the increasing rate of the number of households in the five years future and their electrical energy consumption. It was found that the overall energy generation in the Andaman Sea provides the maximum value at Phang-nga compared with the minimum value at Krabi. While in the Gulf of Thailand, the minimum and maximum values are at Bangkok and Rayong respectively. The maximum energy in the Eastern Gulf of Thailand occurred between June to July due to the Southwest monsoon winds. While the maximum energy in the Western Gulf of Thailand occurred between November to April due to the Northeast monsoon winds. Additionally, the maximum energy in the Andaman Sea occurred between December and January because of a period of inclement weather with thunderstorms. The breakeven point of each location is selected to invest in the renewable energy generation.

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