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Simulating a Sea Wave Power Plant for Malaysia

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ABSTRACT

The demand for electricity in Malaysia is growing yearly. Renewable energy from the sea waves is one of the solutions to solve the energy crisis in Malaysia. Malaysia has a long coastline of 4,675 kilometres. Therefore, simulating a sea waves power plant for Malaysia is an interest of this study. This research is aim to identify the suitable locations for installing sea waves power plants in Malaysia and to simulate the total power generated by the sea waves power plant by using Hybrid Optimization Model for Multiple Energy Resources (HOMER). HOMER is a power optimization software and it is used to simulate and analyze the sea waves power plant in the generation system. The sea wave height, the period, and the water depth are collected from the selected regions. From the results, it shows that the sea waves peak periods are between 3 s and 5 s whereas the wave heights are between 0.5 m and 1 m respectively. The HOMER and analytical results show that the total rate of electrical power connected to the grid for Malaysia is 1408.81 MWh per year and 1408.89 MWh per year, respectively.

1. Introduction

Fossil fuels are sources of electricity generation for many years ago. Therefore, fossil fuels are used in power plants to meet electricity demand. Increasing the use of fossil fuels may result in global warming. Most countries have switched to alternative sources for power generation, for example, the United Kingdom, Portugal, Japan, and others [1-5]. The total population of Peninsular Malaysia is 31 million. The total electric energy consumed by them is 82%. The average annual population growth rate is 1.8% [6]. Malaysia is rich in renewable energy such as biomass, wind, solar, hydro, and sea, waves [20,22,23]. Sea waves energy can be converted into electrical energy. The sea wave heights around Malaysia have a range between 0.3 m and 1.5 m [7]. Since Malaysia wave height is moderate and needs modified wave devices to extract sea waves energy from lower waves heights.

The locations for sea wave power plants will be selected from Peninsular Malaysia, Sabah, and Sarawak. For simulation, the research on the previous article and project was done to choose the possible location to simulate sea waves power plant. One of the selected places are from Kapar,

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Tanjung Karang, Merang, Kuching, Alor Star, Kota Belud, Pulau Jambangan, Bandar Seri Begawan, and Semporna [8-10]. The latitude and longitude on the sea wave converter on the selected location will be mention on the result. Figure 1 shows the potential location for simulating sea waves power plant in Malaysia.

The load demand data are obtained from Single Buyer Berhad. These data are collected from the week ahead demand forecast. The monthly average load (kWh/d), storage capacity, and scaled annual average (kWh/d) is calculated based on these data. The Hybrid Optimization Models for Energy Resources (HOMER) power optimization software by National Renewable Energy Laboratory used to simulate and analyze the sea waves power plant in the generation system. The component needed to simulate the sea waves power plant will be replaced with a micro-hydropower plant model. The analysis focused on the total power generation by sea waves power plant in Malaysia. The sea waves power plant places to be simulated based on the characteristics of sea wave height and its period [15-16]. The study focused on the implementation of HOMER software to compute the power generated in the selected area of research in Malaysia. The chosen location based on the previous study and the water depth of the site. In order to start this simulation, the actual parameters for load demand, sea waves height and period, type of sea wave generator, head, efficiency, and water depth on the selected locations are required.

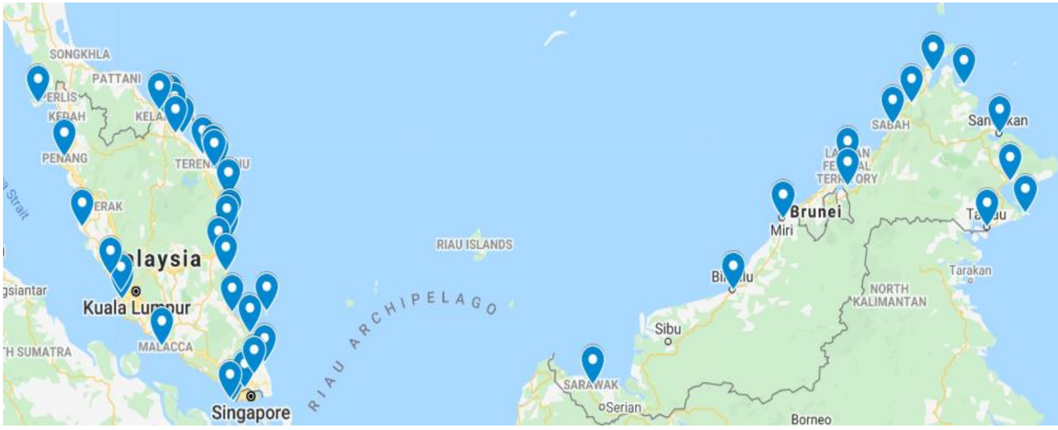

Fig. 1. Potential location for simulating sea waves power plant

2. Methodology

This part will portray the strategies in this study. The following are the three stages used throughout this study:

(i) Stages 1: Project planning
(ii) Stages 2: Project study
(iii) Stages 3: Project simulation

Project planning is the most essential to develop the project because it involves all the procedures from the project naming to the end. It also functions as a guideline for project execution. At this stage, the project title was chosen after discussing it with the supervisor. From the discussion, the problem statement, objective, scope, limitation, and expected outcome have been identified to develop this project. The HOMER software will be used to simulate the total power generated by sea waves power plant.

In this stage, the process is to study the project to be developed and chosen software. Thus, will make user working on HOMER software become simpler because the knowledge of the software was learned. The books, research report, journal, and thesis are used during the studies to obtain the data for this simulation project. A few websites linked to this project have been surf to get more data to develop this simulation project [17-18].

In the simulation stage of the project, the parameter needed in the sea wave converter is specified. The HOMER software will then be used to model and simulate the sea waves power plant.

The study starts with conducting the literature review on the characteristic of location for sea waves power plant to be installed, wave height and period for the selected locations, sea waves water depth and its efficiency. The study on load profile from the Single Buyer needs to calculate the average monthly load, storage capacity, and minimum load ratio data for each state before being inserted to HOMER software. The sea wave height and period data were converted into a hydroelectric resource because the available model in HOMER software is Hydroelectric Power Plants. After the simulation, then start the discussion on the result of power generation on the selected locations. Figure 2 shows the process flowchart for the study.

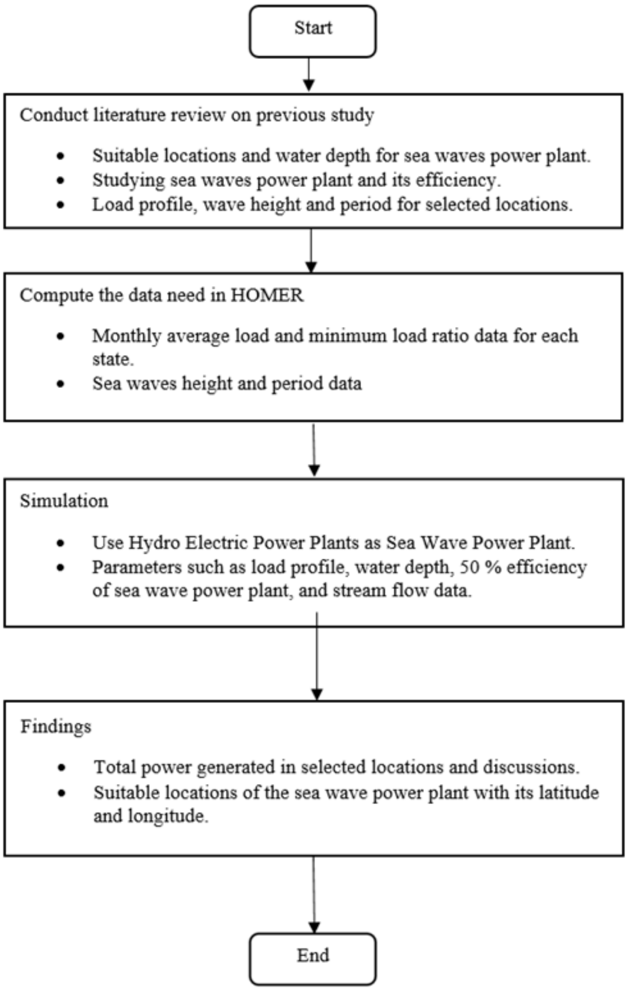

Fig. 2. Process flow chart

2.1 Estimation Wave Height

The significant sea wave height, Hs (m), is equal to four times the elevation of the sea surface (RMS), H_{rms} (m) [8]. It also can be found by multiplying the square root of the variance of the spectrum m_0 by four.

$$H_s = 4\ H_{rms} = 4\sqrt{m_0} \tag{1}$$

2.2 Estimation Wave Period

The peak period, T_p in second, is shown in Eq. (2). According to Muzathik *et al.,* [10], the relationship between the energy period, T_e (s) and other wave period measurements depends on the spectral distribution of the components' waves. m_{-1} is the first spectral moment (mean frequency).

$$T_p = \frac{1}{f} \tag{2}$$

$$T_e = \frac{m_{-1}}{m_0} = 0.9\ T_p \tag{3}$$

2.3 Estimating Power from Sea Wave

The power, P [W/m] from sea waves is shown in the Eq. (4) where $\rho\ [kg/m^3]$ is the density of seawater g [m/s^2] is the acceleration due to gravity [2,10].

$$P = \frac{\rho g^2}{64\pi}\ {H_s}^2 T_e \approx (500) {H_s}^2 T_e \tag{4}$$

2.4 Estimating Power from Sea Wave

Power generated by the sea wave power plant is shown in the Eq. (5) where the Real Plant with length is $L\ [m]$ and the efficiency of sea wave power plant is n_w [2-14].

$$P_w = PLn_w \tag{5}$$

2.5 Estimating Power Generated by Hydroelectric Power Plant

Power generated by a hydroelectric power plant is given in Eq. (6) where the flow rate is $Q\ [m^3/s]$, the available head is $H\ [m]$, the specific weight of water is $\gamma\ [N/m^3]$ and the total efficiency of the hydroelectric power plant is n_{hyd} [6].

$$P_{hydro} = \gamma Q H n_{hyd} \tag{6}$$

2.6 Estimation for Stream Flow

Stream flow was derived from the equation power generated by sea wave power plant and hydroelectric power plant run-on-river shown in the Eq. (7) [14]. Stream flow is an input resource for the hydroelectric power plant in HOMER software.

$$\mathrm{Q} = (0.0488)\ H_s^2 T_e \tag{7}$$

2.7 Input Parameters

The following are the input parameters that needed for the HOMER simulation:
(i) Sea wave height and period
(ii) The density of seawater
(iii) Load demand
(iv) Water depth

These parameters are important to calculate the total power generated per year. The sea wave height and the period are collected from the Malaysian Metrological Department. These data were recorded from January 2018 till December 2018. The ships travel and collect these data send it to the Meteorology department for their weather forecast. Table 1 shows the actual data from the ship observation.

Table 1
Actual data from the ship observation

Date	Time (UTC)	Latitude (degree)	Longitude (degree)	Wave Height (m)	Wave Period (sec)
4 Jan 2018	06	3.1	100.6	1.0	3.0
7 Jan 2018	00	2.5	101.5	0.5	2.0
8 Jan 2018	18	3.0	100.7	1.0	2.0
11 Jan 2018	06	2.8	101.0	1.0	2.0
24 Jan 2018	12	2.6	101.3	0.5	3.0
26 Jan 2018	18	3.2	100.5	0.5	9.0
3 Feb 2018	18	3.2	100.5	0.5	3.0

The density of seawater depends on the temperature and the salinity of the seawater. As the temperature increase, density decreases. As the salinity of the water increase, density also increases. The density of the seawater varies at different points to the ocean. The specific gravity is 1.025, which is expressed as σ is 25. Therefore, in this study, the standard density of seawater is 1025 kg/m^3 [5]. The density of seawater is ranging from 1019.5 to 1026 kg/m^3. These values are used in the analytical calculation.

Figure 3 depicts the actual demand forecast in Peninsular Malaysia for January 2018 [3]. These data are used in HOMER simulation for the deferrable load. The water depth data for the selected locations are collected from the Maritime and Port Authority of Singapore from 2001 to 2014. The water depth data also referred from the Malaysian Government charts from 2002 to 2015 [8]. The minimum and maximum water depth are 5 m and 71 m, respectively. The minimum 5 m water depth is near to the land. The distances are ranging between 0.11 km to 2.87 km from the coastline. The water depth is different with respect to geographical land. Both values are used in calculation and simulation to obtain the total power generated from the sea waves power plant. The Wavestar converter is operating at 5 m water depth and producing 100 kW. Therefore, the minimum of 5 m water depth able to generate some electrical power.

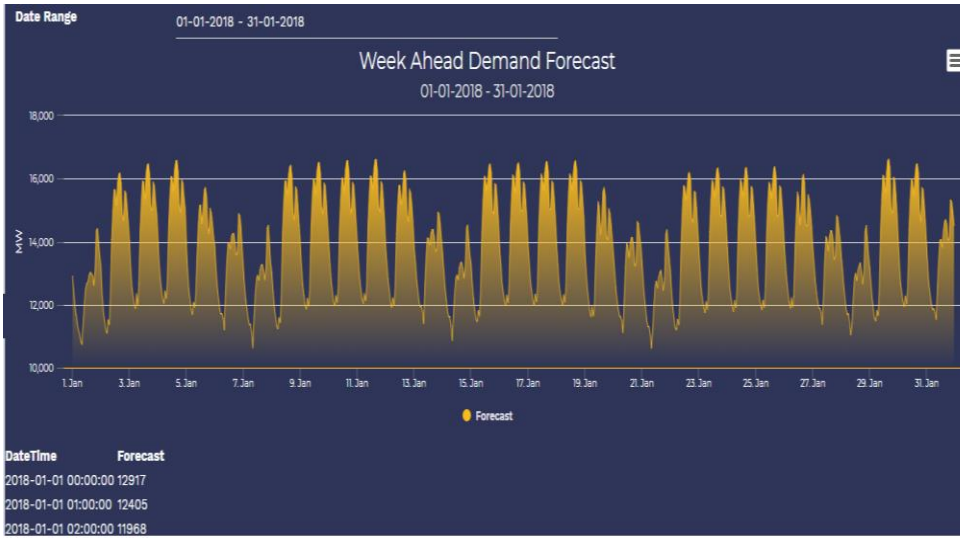

Fig. 3. Load demand data

2.8 Simulation Using HOMER

HOMER is an easy software to be used. HOMER has three core capabilities that are simulation, optimization, and sensitivity analysis. HOMER software is capable of helping the user to simulate all possible deployment scenarios such as residential-scale solar, commercial-scale solar and residential and commercial solar and wind. In HOMER, the optimal possible configuration can be achieved by the optimization process [19]. The load profile data from the single buyer is collected and used to obtain average monthly load, storage capacity, and minimum load ratio. Since in HOMER, the sea waves resource is not available. Therefore, hydroelectric resource is used. The actual parameters, such as sea wave height and period, are used to calculate streamflow for hydroelectric resource. These parameters are collected from the Malaysian Meteorological Department [21]. Figure 4 shows the sea waves system and Figure 5 illustrates the process flow in HOMER.

The specifications for the turbine used in Hydroelectric resources are taken from Silva *et al.,* [14]. The suggested specification for design flow rate and minimum flow ratio are 50. The available head in hydroelectric resource represents the sea waves water depth. The power take-off efficiency and water depth are 50 % and 5 m, respectively [14]. Figure 6 shows the turbine specification.

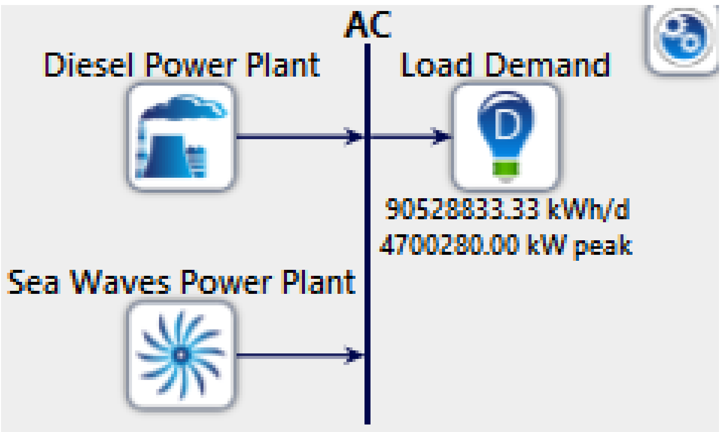

Fig. 4. Sea waves system

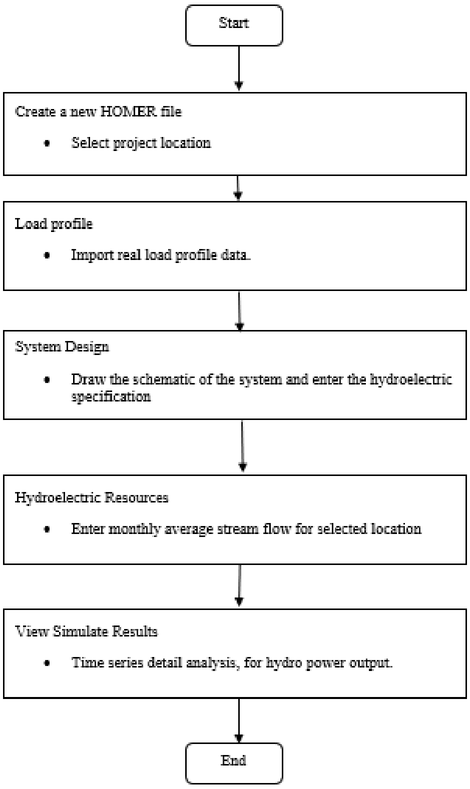

Fig. 5. Process flow in HOMER

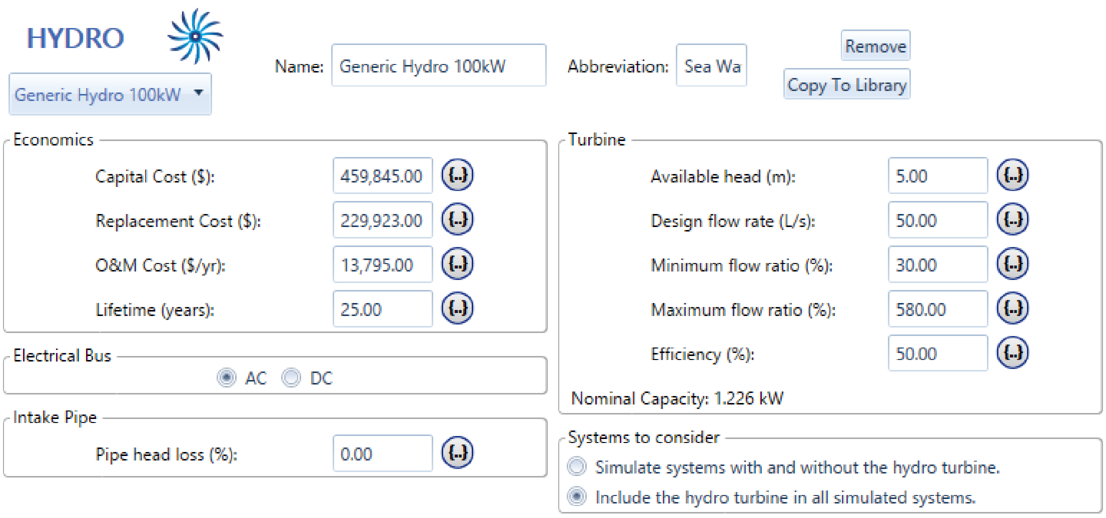

Fig. 6. Turbine specification

Figure 7 shows the streamflow data for Selangor. The Eq. (7) is used to calculate the streamflow, Q in (L/s). The streamflow data were computed for all the selected sites. The streamflow is used to convert from m^3/s to L/s and this is shown in Table 2. The reason for converting is, in HOMER, the streamflow data was in L/s. If we vary the seawater density accordingly, then the actual power per meter, available sea waves energy, energy produced by the sea wave power plant and the output power for monthly can be computed. This is shown in Table 3. The results then will be compared with HOMER. The sea waves height and period data in January 2018 for Selangor are used in Table 2 and Table 3.

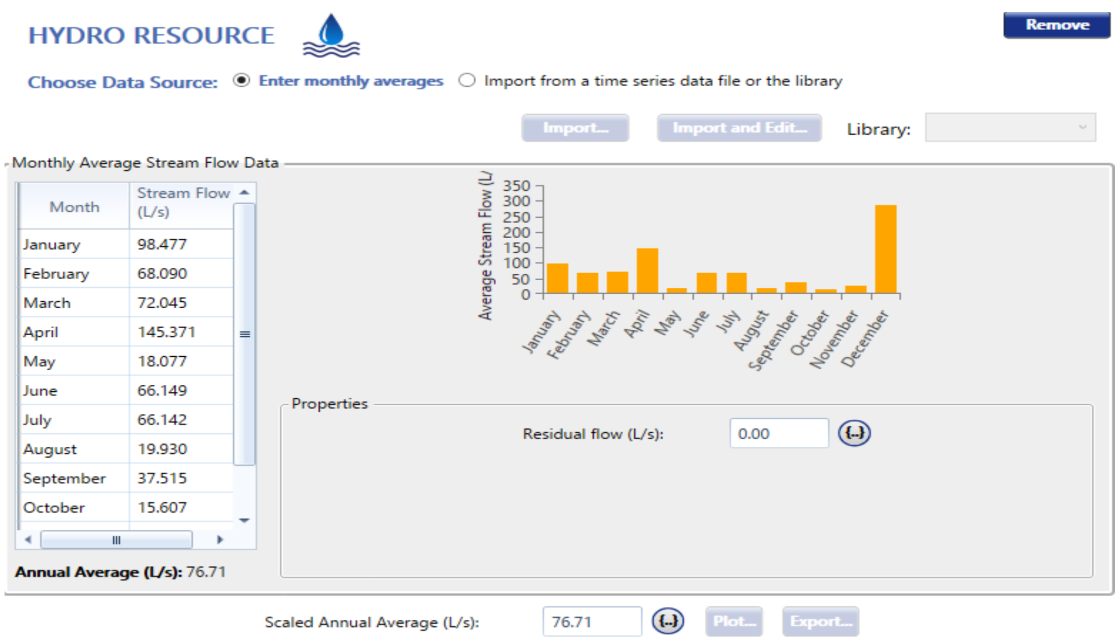

Fig. 7. Streamflow data for Selangor

Table 2
Resource for HOMER software

Parameter	Calculation
Flow rate Calculation, Q	$Q = 96.075$ L/s

Table 3
Output parameters calculation for Selangor in January 2018

Output Parameters \Equation	$P = \frac{\rho g^2}{64\pi} H_s^2 T_e$	$P = (500) {H_s}^2 T_e$
Seawater Density	1025 kg/m^3	1045 kg/m^3
Available Sea Waves Power per month per meter	$P = 965.8788782\ W/m$	$P = 984.375\ W/m$
Available Sea Waves Energy per month per meter	$P = 718{,}613.8854\ Wh/m$	$P = 732{,}375\ Wh/m$
Energy Produce by Sea Wave Power Plant	P_wav = 1,796,534.713 Wh	P_wav=1830937.5 Wh
Output Power Monthly Average	P=2414.697196 W	P = 2460.9375 W

3. Results

3.1 Power Plant Potential Locations

The potential locations for the installation of sea wave power plants have been identified and plotted as shown in Figure 8 and Figure 9. Tanjung Kamuning, and Bachok are located near the coastline of Peninsular Malaysia. The distance from the coastline to Tanjung Kamuning and Bachok are 0.09 km and 6.72 km, respectively. Both locations have seawater depths of 10 meters. This distance is calculated using the Sea Navigation Chart and Fishing Map [8]. Depth of seawater has different depths depending on geographical location. Table 4 shows more detailed potential locations for the installation of sea wave power plants in Malaysia. Kota Kinabalu and Kota Belud are located near the coastline of Sabah. The distance from the coastline to Kota Kinabalu and Kota Belud are 0.07 km and 0.06 km, respectively. The water depth for Kota Kinabalu is 9 m and Kota Belud is 11 m.

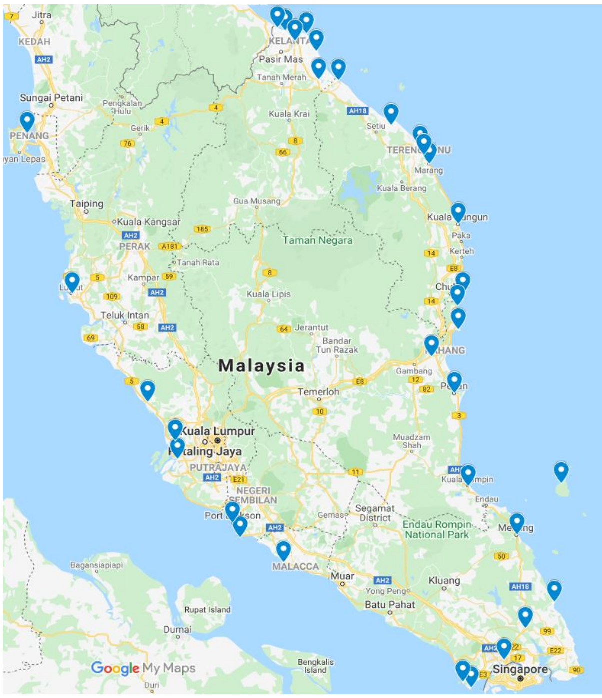

Fig. 8. Potential locations in Peninsular Malaysia

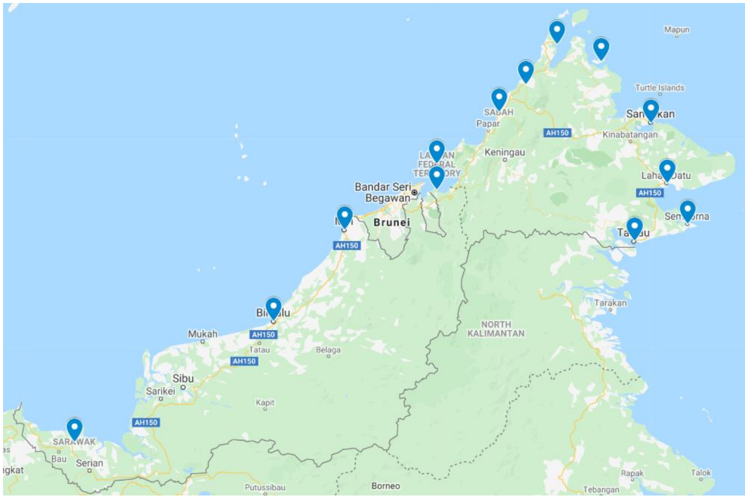

Fig. 9. Potential locations in Sabah and Sarawak

Table 4
Locations of the sea wave power plant

States	Locations	Latitude	Longitude	Distance from Land (KM)	Water Depth (m)
Perlis	Pulau Langkawi	6.3011	99.7978	0.13	5 to 7.3
Perak	Lumut	423118	100.5915	0.11	5 to 10
Selangor	Port Klang	3.0718	101.3498	0.85	5 to 10
	Kapar	3.1046	101.3193	1.06	5 to 10
	Tanjung Karang	3.4233	101.1133	2.87	5 to 7.3
Terengganu	Merang	5.5405	102.9428	0.39	5 to 10
	Besut	5.836	102.5712	1.83	5 to 10
	Setiu	5.6592	102.763	0.80	5 to 10
	Kuala Terengganu	5.3845	103.1511	3.41	10 to 20
	Marang	5.2385	103.2186	2.65	10
	Kuala Dungun	4.7995	103.4495	0.91	20

	Kemaman	4.2571	103.4685	0.48	10 to 20
	Cendering	5.29694	103.1913	2.48	10
Pulau Pinang	George Town	5.4228	100.3449	0.17	5 to 10
Melaka	Tanjung Keling	2.2249	102.1443	0.61	5
Pahang	Tanjung Gelang	3.9646	103.4406	0.13	8
	Pantai Cherating	4.1229	103.4414	4.26	10
	Kuantan	3.9909	103.4252	0.37	10
	Pekan	3.5115	103.499	2.65	10
	Rompin	2.7781	103.5459	1.48	7
	Tioman	2.8	104.25	3.94	24
Johor	Tanjung Sedili	1.9052	104.1368	1.85	7
	Tanjung Piai	1.2588	103.5121	0.61	9
	Johor Baharu	1.4557	103.7508	0.15	5 to 10
	Mersing	2.4023	103.9293	4.78	10
	Kota Tinggi	1.56555	104.0216	0.28	9
	Kukup (SELAT)	1.2586	103.5009	1.06	10
Kelantan	Pantai Sabak	6.1986	102.3308	2.59	9
	Tumpat	6.2303	102.1466	1.19	5 to 6.8
	Kota Bharu	6.2061	102.2864	1.67	5 to 7.6
	Bachok	6.0508	102.4585	6.72	10
	Pasir Puteh	5.9276	102.5083	5.43	10
	Geting	6.2532	102.0965	1.11	5 to 7
Negeri	Tanjung Tuan	2.4129	101.8451	0.46	19
Sembilan	Tanjung Kamuning	2.521	101.78971	0.09	10
Sabah	Labuan	5.3837	115.2588	0.17	5
	Kota Kinabalu	5.9748	116.0569	0.07	9
	Kudat	7.0402	116.7624	0.59	16
	Sandakan	5.9762	118.0804	1.54	5
	Lahad Datu	4.9022	118.6566	2.83	71
	Tawau	4.2157	117.9752	0.87	9
	Kota Belud	6.3728	116.3231	0.06	11
	Pulau Jambongan	6.7626	117.4671	0.67	7
	Semporna	4.5226	118.5703	0.24	5
Sarawak	Kuching	1.7513	110.5099	0.41	9
	Bintulu	3.2441	113.0415	2.67	8
	Miri	4.36	113.9462	1.63	5 to 10
	Kampung Awat-Awat	4.9516	115.2632	2.76	5

3.2 Yearly Sea Waves Energy Available

The sea waves energy available per year for six states' coast have been determined for seawater density of 1025 kg/m^3 and 1045 kg/m^3 [3]. The monthly wave energy calculation by using the seawater density of 1025 kg/m3 is shown in Table 5. While the monthly wave energy calculation by using the seawater density of 1045 kg/m^3 is shown in Table 6. Figure 10 shows the comparison of yearly sea wave energy available for these states' coasts.

Table 5
Monthly sea waves energy available for density of 1025 kg/m^3

Month	Selangor	Negeri Sembilan	Pahang	Terengganu	Sabah	Sarawak
Jan	718613.89	28963.562	1354187.9	2424489.2	1050452.7	462650.46
Feb	448785.96	1046057.5	1604650.9	1894396	2368727.4	220220.14
Mar	534561.86	119248.84	893545.04	105414.95	251827.86	276038.98
Apr	1027253.6	441544.63	433816.54	949497.57	405932.82	2390201.9
May	133874.07	628638.86	141353.86	34219.709	232694.02	491559.27
Jun	462993.1	4768682	397390.17	1236325	136466.96	353235.7
Jul	486284.88	491559.27	2248159.3	2544942.6	1671600.8	95775.764
Aug	149162.16	2851642.4	2997975	1506598.7	1233734.6	712043.7
Sep	264926.78	44154.463	76934.736	447063.94	535958.18	25432.971
Oct	110494.07	83847.229	421102.44	198565.56	129465.84	34791.315
Nov	181699.5	566567.82	363612	264926.78	1990050.5	298724.37
Dec	2075356.9	1168032.7	684394.18	2566478.2	2124421.9	1589984.6
Total	6594006.7	12238939.3	11617122.12	14172918.1	12131333.6	6950659.1

Table 6
Monthly sea waves energy available for density of 1045 kg/m^3

Month	Selangor	Negeri Sembilan	Pahang	Terengganu	Sabah	Sarawak
Jan	732375	29518.2	1380120	2470917	1070568.4	471510
Feb	457380	1066089	1635379.2	1930672.8	2414087.4	224437.25
Mar	544798.46	121532.4	910656	107433.6	256650.24	281325
Apr	1046925	450000	442123.92	967680	413706.24	2435973.1
May	136437.7	640677	144060.72	34875	237150	500972.4
Jun	471859.2	4860000	405000	1260000	139080.24	360000
Jul	495597	500972.4	2291210.5	2593677	1703611.2	97609.824
Aug	152018.54	2906250	3055384.8	1535449.3	1257360	725679
Sep	270000	45000	78408	455625	546221.52	25920
Oct	112609.98	85452.864	429166.36	202368	131945.05	35457.552
Nov	185178.96	577417.32	370575	270000	2028159	304444.8
Dec	2115099	1190400	697500	2615625	2165103.6	1620432
Total	6720278.8	12473309.2	11839584.5	14444322.7	12363642.9	7083760.9

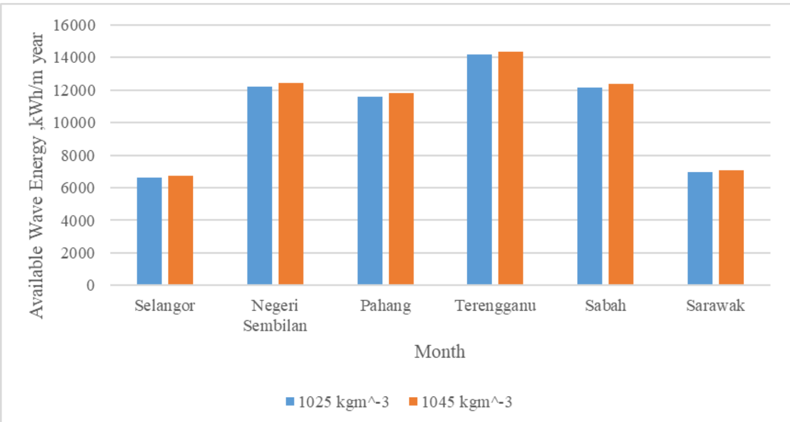

Fig. 10. Yearly sea waves energy available for six states coast

3.3 Stream Flow Results

Table 7 and Figure 11 illustrate the monthly average streamflow data for these states. The data shown are the result of conversion m^3/s to L/s from Eq. (7). This data is then entered into the hydroelectric resource in the HOMER software.

Table 7
Monthly average streamflow

Month	Selangor	Negeri Sembilan	Pahang	Terengganu	Sabah	Sarawak
Jan	96.08	3.78	181.26	322.16	140.44	61.85
Feb	66.43	153.66	235.57	277.93	352.98	32.81
Mar	70.29	16.27	119.46	13.73	33.97	36.91
Apr	141.83	61.00	60.70	131.17	55.43	328.67
May	17.64	84.72	19.15	4.58	31.05	65.07
Jun	64.54	658.80	54.90	170.80	19.12	48.80
Jul	64.53	65.07	299.61	338.89	224.08	12.63
Aug	19.44	381.25	398.53	199.27	164.70	95.20
Sep	36.60	6.10	10.84	61.76	74.32	3.51
Oct	15.23	11.02	55.77	26.55	17.35	4.83
Nov	25.31	77.47	50.33	36.60	272.61	40.66
Dec	280.13	156.16	91.50	343.13	286.23	212.57

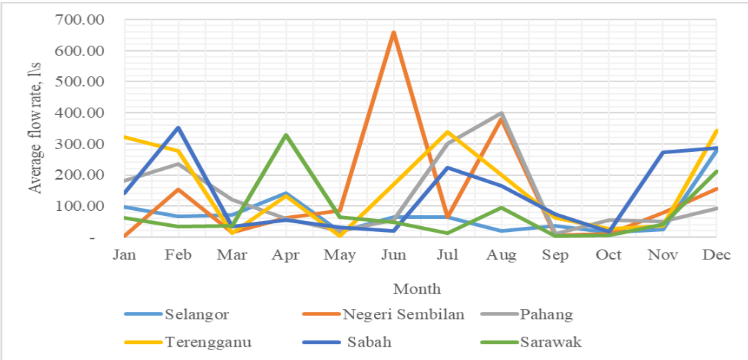

Fig. 11. Monthly average streamflow

3.4 Total Rate of Electrical Power Generated

The total rate of electrical power generated by the sea waves power plant has been calculated and compared with HOMER results. Three selected sites in Selangor have a water depth of 5 m, 7 m and 10 m. The rate of electrical power for these three sites generates about 72534.074 kWh/y. Similarly, a calculation can be performed for other sites in the states Table 8 shows the total rate of electrical power generated in the year 2018 for six states in Malaysia. Table 9 and Figure 12 show the total rate of electrical power generated on the selected site. More electrical energy can be harvested from Sabah and Terengganu.

Table 8
Total rate of electrical power generated with different depth of seawater

States	Water Depth (m)	Energy Production by HOMER (kWh/y)	Energy Production by Calculation (kWh/y)
Selangor	5	16078	16485.020
	7	22509	23079.020
	10	32155	32970.034
Negeri Sembilan	5	29781	30597.348
	10	59561	61194.697
	19	113166	116269.924
Pahang	5	28244	29042.805
	7	39542	40659.927
	8	45191	46468.488
	10	56489	58085.611
	24	135573	139405.465
Terengganu	5	34492	35432.295
	10	68983	70864.590
	20	137966	141729.181
Sabah	5	29939	30328.334
	7	41915	42459.668
	9	53891	54591.001
	11	65866	66722.335
	16	95806	97050.669
	71	425137	430662.344
Sarawak	5	16892	17376.648
	8	27027	27802.636
	9	30405	31277.966
	10	33784	34753.296
Total		1640392	1675309.302

Table 9
Total rate of electrical power generated on the selected site

Selected Sites	HOMER (kWh/yr)	Calculation (kWh/yr)	Number of Selected Site
Selangor	86819	89019.09	3
Negeri Sembilan	172727	177464.6	2
Pahang	389773	400790.7	6
Terengganu	758813	779510.5	8
Sabah	826323	837062	9
Sarawak	108108	111210.5	4
Total	2342563	2395057	32

Fig. 12. Total rate of electrical power generated on the selected site

4. Conclusions

The suitable locations for installing the sea waves power plant have been identified. From the results obtained that the sea waves have peak periods between 3 s and 5 s and wave heights between 0.5 m and 1 m. The sea wave height, period and depth from the selected region are used in the simulation and analytical calculation. In this study, the sea waves power plant used 50% efficiency. The HOMER and analytical results show that the total rate of electrical power connected to the grid for Peninsular Malaysia is 1408.81 MWh per year and 1408.89 MWh per year, respectively. The results are approximately the same. The results obtained are satisfactory. It can be concluded that HOMER software can be used as simulation software for sea waves power plant.

For future research, the study has several recommendations such as instead of using voluntary ship observation measurement data for sea waves height and period from Malaysian Meteorology Department for this research, attempt using buoy type measurement and satellite altimetry data for sea wave height and period compared with the findings in this research. Instead of using Wavestar model compare to HOMER and calculation result, attempt using another model of sea waves power plant as a comparison. Instead of finding total rate of electrical power generated, attempt adding a few more finding for average cost per kWh, operating cost and initial coast for sea waves power plant.

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