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Article

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Potential of Small-wind Turbine for Power Generation on Offshore Oil and Gas Platforms in Malaysia

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ABSTRACT

On most of the offshore oil and gas platforms, the current means of generating power are through the use of generators i.e. gas turbines and diesel power generators, or micro-generators for some smaller equipment. These generator sets are less reliable, especially on unmanned platforms. Hence, the deployment of renewable energy, such as the use of wind turbines, would be better for energy security, economic development and also protection of the environment. Instead of using wind power to power up the whole platform, small wind turbines can be utilised to power up some utilities and instrumentations on the platform, while having generators as back up, as the wind speed is beyond control. However, the capability of a small wind turbine in generating enough power is constantly under doubt as it is yet to be widely employed and only meagre data is available. This is caused by the issue of having insufficient studies regarding the implementation of small wind turbines for power generation on offshore oil and gas platforms. Hence, this paper studied the capability of small wind turbines for power generation on offshore platforms in Malaysia. Several models of small wind turbines were selected and their abilities in generating power to fulfil the annual energy consumption on a typical offshore platform were examined through precise calculations. The common offshore locations in Malaysia were identified and the average wind speeds from 2017 to 2019 at these locations were analysed. The result shows that certain models of small wind turbines are able to provide a significant amount of power for an offshore platform especially to power up the low power machineries. It was found that Kerteh, Terengganu is the most suitable offshore location to harness wind power due to its averagely high wind speed throughout the year. The highest amount of energy that can be produced was around 1445kWh per annum at Kerteh by the small wind turbine with the largest swept area and the lowest cut-in speed. This paper aims to serve as numerical validation on the plausibility of integrating small wind turbines for the generation of electricity on offshore platforms in Malaysia while also providing the recommended locations that are suitable for this region.

Keywords: Small Wind Turbine, Offshore Platform, Micro-Generation, Kerteh, Wind Energy
JEL Classifications: Q42, Q47, Q56

1. INTRODUCTION

Offshore oil and gas (O&G) platforms are conventionally equipped with power supply based on fossil fuel such as gas turbines and diesel generator sets (Aardal et al., 2012). The power generated is used for offshore oil and gas exploration and production activities which require energy not just to power their main and supporting activities but also instrumentation and utility supply. However, the unreliability of them-the bulky size of generator sets, the vibration noise of diesel engines, the risks of diesel generator explosions, and the cost considerations due to the continuous use of diesel fuel, these may affect the energy production rates. Wind energy is an option to replace them to produce cleaner and safer energy. The alternative to constructing an offshore wind farm that occupies a coastal area and may harm marine animals are small wind turbine (SWT) installed on offshore platforms for microgeneration that combined with other renewable energy sources in a hybrid system to ensure a smooth and stable supply. However, some of the O&G

operators in Malaysia doubt a SWT's ability in producing sufficient power for the equipment on O&G platforms. O&G consultants who design platforms for the operators that intend to employ SWT on the platforms for safety and cost considerations may be met with disagreements from the operators. As the application of SWTs installed on platforms is unpopular compared to large wind turbines (LWTs) in offshore wind farms, the reliability of SWT for power generation is not fully understood yet. The root of these issues is the insufficient studies regarding the implementation of SWT) for power generation on offshore oil and gas (O&G) platforms. Thus, a research on the application of SWT on offshore O&G platforms was conducted to ascertain its reliability for power generation and its applicability in Malaysia.

2. EQUIPMENT ON AN OFFSHORE OIL AND GAS (O&G) PLATFORM

An offshore platform can be intended for oil or gas exploration, can have or have no living quarter platform, can perform processing or can be just a wellhead platform, can include or exclude an oil recovery package (Samie, 2016). Hence, the equipment and facilities installed on an offshore platform depend on the platform's function and crude composition. The choice of categorisation of equipment solely based on the platform's owner and developer's decision according to the intended usage of the platform. The equipment can be categorised into process system, utility system, instrumentation and control system, safety system, and accommodation system (Samie, 2016). Tables 1-5 summarises the equipment involved and the function of each system and equipment.

3. OFFSHORE RENEWABLE ENERGY POTENTIAL

Solar systems have been employed at oil and gas field locations in the United States of America (USA) for oil and gas field productions (Choi et al., 2017). A recent study has quantified the improvement due to single axis tracker technology (Dawoud and Lim, 2021). A 300MW, 29MW, and 7MW solar thermal systems are applied to generate electricity for different gas field locations to provide thermal energy for the required production activities at gas production sites too. A few of 5MW wind turbines were built and they supply 30% of the total power demand on a platform in the United Kingdom (UK) (Choi et al., 2017). Among all of the offshore renewable energy sources, offshore wind energy has the most developed states in terms of capacity, technology, and policies (Appiott et al., 2014). Due to this, offshore wind energy has the greatest potential for efficient energy production, grid integration, and environment protection as compared to the other marine renewable energy resources. Although offshore wind projects are more complicated and expensive to install and maintain than onshore wind projects, offshore wind is typically faster and steadier hence results in greater electric power generation. In addition, the exploitable offshore wind in the world was estimated to be about 74,000 GW which is 30 times higher than the average electric power generation (Appiott et al., 2014). The North Sea region is currently the front-runner in offshore wind, in terms of installed capacity and technical capability (Appiott et al., 2014). As offshore wind turbines interact with oncoming wind, the more stable the air patterns are, the more consistent the power output generated. As wind depends on the atmospheric pressure, the wind resource is not predictable. However, the use of offshore wind turbines with long fetch lengths results in faster and steadier wind as compared to the extraction of wind power at onshore sites (Cathlyn and Bryony, 2018). There are two types of foundation structures for offshore wind turbines namely the fixed bottom foundation and the floating foundation. The development and deployment technologies of floating wind turbines are still in its early stage while fixed bottom offshore wind energy technology is considered as the most mature technology in the offshore renewable energy industry (Cathlyn and Bryony, 2018).

Ocean energy can be classified into tidal energy, wave energy, ocean current energy, ocean thermal energy conversion (OTEC)

Table 1: Equipment of process system (Samie, 2016)

Process system – process, treat and transport the crude	
Equipment	**Function**
Xmas (Christmas) tree	Protect topside equipment from the pressure of reservoir
Production header	Collect fluid from wells and guide them to the equipment
First-phase separator	Separate the gas, hydrocarbon, and water in crude
Slug catcher	"Catch" the slug and sand in the crude
Sand management system	Transfer the sand in oil or gas platform to the topside via crude
Dehydration package	Absorb the remaining water vapour left by the separator in the crude gas
Sweetening system	Absorb CO_2 or H_2S in the crude gas
Oily water treatment system	Filter the oil from the water reservoir before discharging the water to an open drain system
Chemical injection system	Inject chemicals to crude to prevent hydration, corrosion and etc.
Flare system	Separate associated gas separated from oil to be used in power generation, transferred to onshore, or injected to reservoir to boost oil production
Closed-drain system	Route non-hazardous drain to the sea
Fuel gas treatment	To process the associated gas from crude or gas directly from header to be used as platform fuel
Compression system	Force air into the system to produce suitable pressure for the operation of pneumatic instrument
Water injection system	Inject water to bring crude oil up to the surface when the pressure of reservoir reduces
Pig launching and receiving system	Clear water or slug to prevent the blocking of pipeline where the final product of each platform is directed to
Electrical submerged pump	Lift fluids from wellbores (an artificial lifting method)
Export meter	Measure oil and gas

Table 2: Equipment of utility system (Samie, 2016)

Utility system – power and facilitate the process system without affecting the crude	
Equipment	**Function**
Wellhead control panel and hydraulic power unit (WHCP/HPU)	Supply hydraulic force for the operation of actuators of main valves
Compressed air system	Supply power for pneumatic instrument
Diesel oil system	Provide fuel to generate power
Power generation system	Supply electricity to all equipment
Electrical power storage facility	Ensure uninterrupted power supply
Inert gas	Prevent the intrusion of air to inflammable spaces
Atmosphere vent	Disperse gas into a safe area
Open drain	Provide a stilling place to separate the oil from water that is to be discharged to the sea
Hypochlorite system	Prevent the growth of algae in the piping system
Service seawater	For housekeeping
Pedestal crane	Transfer spare parts, chemicals, fuels and food from supply boat
Material handling system	Move equipment, spare parts, and materials on the platform

Table 3: Equipment of instrumentation and control system (Samie, 2016)

Instrumentation and control system–monitor and control all equipment on the platform	
Equipment	**Function**
Process control system	Receive signals regarding the operation of equipment such as start/stop and open/close
Emergency shutdown system	Receive signals regarding emergency conditions that lead to platform shutdown
Fire and gas system	Receive signals regarding safety hazard and control fire and gas detectors
Choke valve	Adjust well pressure fluctuation
On/off valve	Use for shutdown, blowdown, and isolation of packages
Motorised valves	Use for the control of actuators

Table 4: Equipment of safety system (Samie, 2016)

Safety system–eliminate hazard, extinguish fire and rescue staffs	
Equipment	**Function**
Firefighting equipment	Extinguish fire actively
Fire barrier	Prevent collapse of structures and limit effect of helicopter fire
CO_2 total flooding system	Extinguish fire by flooding CO_2 above oxygen, preventing it to reach the top
Dry chemical extinguishing system	Extinguish helideck fire
Lifeboat	Move staffs away from platform during fire
Safety shower	Wash off crude oil splashed on body
Oxygen breathing apparatus	Prevent the intake of toxic gas released

power, salinity gradient power and energy from marine biomass (Chong and Lam, 2013) (Appiott et al., 2014). The World Offshore Renewable Energy Report 2004-2008 estimated that 3000GW of tidal resource is available. However only <3% of the tidal energy is located at the suitable areas that allow power generation. Compared to tidal energy, wave energy is less suitable in Malaysia due to the average annual wave power density that is <50kW/m^2 (the requirement of a wave energy converter) in Malaysia's ocean (Chong and Lam, 2013). Under-water turbine technology could be used to harness the enormous amount of untapped ocean current energy from the large ocean currents at the Gulf Stream off the east coast of the USA and Japan (Appiott et al., 2014). Sabah, Malaysia has the potential to harness the ocean thermal energy at the Sabah trough where the water depth is 2900 m and the surface temperature is 29°C while the bottom temperature is 3°C (Chong and Lam, 2013). Due to the high rainfall rate in Malaysia which is around 250 cm per year, the main rivers at the west coast of peninsular such as Sungai Selangor and Sungai Perak are drained into the Straits of Malacca and result in the exchange of nutrients at the mouth of the river thus producing salinity gradient (Chong and Lam, 2013). Yet, most of the technology to harness ocean energy is still at the research and development level.

A few renewable sources can be combined and form a hybrid renewable energy system to ensure a smoother and steadier supply. The capability of the combination of wind and solar power to generate power for offshore application on a platform in Sabah was researched in (Tiong et al., 2015). In (Kalogeri et al., 2017), the combined exploitation of offshore wave and wind energy was studied. It was found out that the most suitable location for this is the western part of offshore areas in the Europe.

4. WIND TURBINE GENERATION FOR OFFSHORE PLATFORM

Large wind turbines (LWTs) can either be installed individually or grouped as a wind farm that can be connected to a utility power grid or even combined with other renewable energy sources such as wave energy or solar energy to form a hybrid power plant (Kumar et al., 2016). Offshore wind power systems typically use larger wind turbines to build power plants such as the use of Statoil Hydro's turbine that is 700 m deep and based on a floating foundation to supply the North Sea oil installations (Kumar et al., 2016). In (He et al., 2013), the feasibility of offshore wind farms with LWTs to act as power source to offshore oil and gas (O&G) platforms was studied and it was concluded that the three cases of applications and connections of the offshore wind farms to O&G platforms are economically and technically feasible based on the theoretical analysis conducted.

The environmental impacts of offshore wind farms were summarised in (Vaissière et al., 2014). The impacts caused during the construction of an offshore wind farm is more intense but happen for a shorter duration as compared to the operation phase. During the construction phase, species living on the seabed are affected during the underwater cable installations, material from the stirred-up sediment may reduce the light penetration and photosynthesis hence affecting the trophic chain balance and the underwater vibration and noise during the construction may affect marine animal's health too. The impacts during the operation phase are less intense but will be permanent over the entire lifetime of the wind farm. The use of LWTs leads to the risks of collision which may harm birds during poor visible periods such as nigh time or bad weathers.

Other than LWT, small wind turbine is also available and has recently been explored in terms of its potential application to power up TELCO towers in Malaysia (Lim et al., 2019). A SWT, SD3EX specially designed and manufactured by SD Wind Energy to be used in the power generation of O&G field and it has been functioning effectively in the North Sea for more than a decade (Turbine, 2006). SD3EX is an ATEX approved SWT that has a power rating of 3kW, diameter of 3.9 m and a cut-in speed of 2.5m/s. Another use of SWT for offshore platform power generation is the Airdolphin Mark-Zero SWTs which are used build a mini wind farm on the platform and utilised as an off-grid power source for the unmanned platform (Zephyr Corporation, 2012).

5. METHODOLOGY

Figure 1 shows the overall flowchart of the research study.

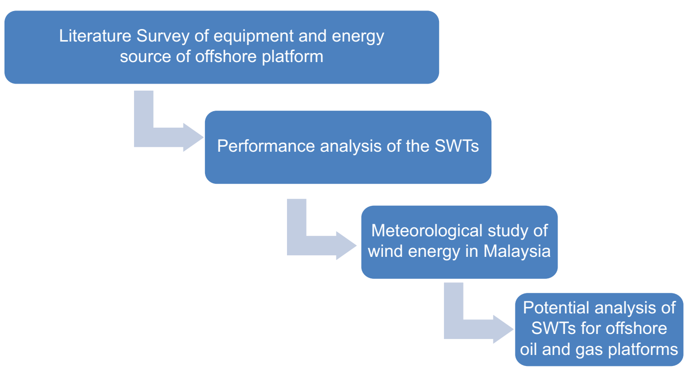
Practically, SWTs will not be used to supply all of the facilities on a platform as many turbines will have to be installed due to the limited power capacity of a SWT. The SWTs installed on a platform will only be used to power up some of the equipment. Instead of determining the percentage of power that can be supplied by SWTs to the whole platform, knowing the type of equipment that can be sufficiently supplied by SWTs is more useful as the SWTs might not be able to supply every each of the equipment on the platform. Hence, the equipment list obtained was categorised into three groups-"High," "Intermediate" and "Low" based on their daily energy consumption. The equipment was first arranged in descending order in terms of their daily energy consumption before categorizing them into different categories as shown in Table 6 (Science Direct, 2020).

There are different types of SWTs available in the market. Different models of SWTs may have different rotor radius, cut-in speed, power rating, input voltage, certifications and etc. However, not all of the SWTs can be used on offshore O&G platforms. An offshore O&G platform consists of potentially explosive atmosphere and the equipment used on the platform need to be explosion-proof. Explosion-proof equipment is equipment that is capable of enduring explosion. There are a few international standards to ensure the safety of equipment being used in an explosive environment. In Malaysia, the standards and certifications that are commonly used are ATEX and IECEx certification. However, in Malaysia, there is no strict rule regarding the need of using of explosion-proof SWT on an offshore platform, the choice of SWT depends on the client's preference. In the research conducted, the types of SWT chosen are SWT with ATEX or/and IECEx certification and SWT without explosion-proof certification but is currently being used by several offshore platforms in Malaysia. The SWT selected also has to be a 24Vdc wind turbine as the equipment list used in this research was initially connected to a 24Vdc solar panel. Four models of SWTs were selected for the research and the significant specifications of the selected wind turbines which are the rated power, rotor diameter, cut-in speed, cut-out speed and certifications on ATEX/IECEx were recorded. In order to analyse the performances of the SWTs selected for the project, the power that can be generated by different SWTs at different wind speeds were calculated. The power extracted by a wind turbine at different wind speeds were calculated by using the equations in (Kalmikov, 2017):

$$P_T = 0.5 \rho A v^3 C_P \quad (1)$$

Where
R-turbine radius (m)
A-rotor swept area (m^2)

Figure 1: Flow of study



AQ5 **Table 5: Equipment of accommodation system (Samie, 2016)**

Accommodation system–facilitate operators and staffs' life and job on the platform	
Equipment	**Function**
Ventilation and air conditioning system	Provide cooling air for motors and oxygen for staffs
Fresh water system	Provide water for the shelter of operators
Sewage treatment system	Treat sewage from shelter before discharging to sea
Incinerator	Burn waste/sewage that is allowed for offshore burning to prevent transferring back to onshore
Helicopter's fuel system	Pump fuel to helicopter to ensure sufficient fuel for return trip

Table 6: Guidelines to categorise the equipment based on their daily energy consumption

Category	Daily energy consumption-DEC (*Wh/day*)	Description (Science direct, 2020)
High	DEC ≥ 2400	• Equivalent to leaving a desktop computer at sleep mode (20 Wh/h) for 120 h (5 days) or more • Equivalent to making at least 60 servings of toast by using a toaster (40 Wh/serving)
Intermediate	400 ≤ DEC < 2400	• Equivalent to leaving a desktop computer at sleep mode (20 Wh/h) for at least 20 h but < 120 h (5 days) • Equivalent to making at least 10 but < 60 servings of toasts by using a toaster (40 Wh/serving)
Low	DEC < 400	• Equivalent to leaving a desktop computer at sleep mode (20 Wh/hr) for less day 20 h • Equivalent to making < 10 servings of toasts by using a toaster (40 Wh/serving)

ρ-air density (typically 1.2 kg⁄m^3)
v-wind speed (m/s)
C_P-power coefficient
P_T-power extracted by the wind turbine (W)

The calculation of the power generated by a wind turbine depends on several parameters – wind speed, rotor swept area (a function of rotor radius), power coefficient, and air density (a function of air pressure, air temperature and humidity). To calculate the power generated by a wind turbine, the rotor swept area was first calculated by applying the formula, $A=\pi R^2$ where R is the radius of the turbine. Cp is the power coefficient that indicate the maximum power that can be extracted by a wind turbine from wind. According to Betz Limit, the maximum possible power that can be converted by the wind turbine is only 0.593 (59.3%) or 16/27 of the total power in the wind. The air density, ρ is usually 1.2 kg/m^3. Hence, to calculate the power generated by SWT1, SWT2, SWT3 and SWT4, several assumptions were made:

Assuming an ideal SWT operation and a usual air atmosphere,
- Cp=16⁄27=0.593 (ideal operation)
- ρ=1.2 kg/m^3 (usual air atmosphere)

These are the important notes in calculating the total energy generated per annum by different SWTs at different locations:
- Wind turbines will start to generate power only after their cut-in speeds are exceeded
- The maximum power that can be produced by each SWT is the rated power
- Only one unit of SWT was involved
- For the calculations of power and energy generation in order to determine the minimum amount of wind power generation that is feasible at each location in Malaysia
- Ideal operation was assumed, hence Cp=16⁄27=0.593
- 2017, 2018 and 2019 were common years, hence there were 28 days in February for these 3 years.

6. RESULTS AND DISCUSSION

In Table 7, the equipment that are normally powered by a solar power system on a typical offshore O&G platform in Malaysia and their energy consumed per day were stated. From the table, it can be seen that the daily energy consumption of different equipment varies and ranged between 72Wh and 3840Wh.

Table 8 shows the selected models of SWTs and the important specifications that were involved in the research project. Referring to Table 8, four models of SWTs, including ATEX or/and IECEx approved SWT and also non-explosion proof SWT that is currently employed on some platforms in Malaysia were selected for the study of their capability to generate power sufficient power for an offshore platform. SWTs that require a 24V battery storage are selected as the electrical load list used in the research project was initially powered by a solar panel system connected to a 24V battery bank.

SWT1 and SWT3 have the lowest cut-in speeds, SWT2 has the highest cut-in wind speed while the cut-in speed of SWT4 is in between. SWTs will start to generate electricity only after its cut-in speed is exceeded. Hence, it is better for a SWT to have low cut-in speed. While for the rotor diameter, SWT1 has the

Table 7: Categories of equipment and the total daily energy consumption

No.	Equipment arranged from highest to lowest energy consumption	Daily energy consumption (*Wh/day*)	Category	Total Daily energy consumption (*Wh/day*)
1	Telecom equipment 1	3840.00	High	17040.00
2	MPFM (Flow computer unit)	3600.00		
3	SIS/FGS Panel-Controller and cards	2400.00		
4	Telecom Equipment 3-PTZ CCTV Camera (Vent Area)	2400.00		
5	Telecom Equipment 3-PTZ CCTV Camera (Boat Landing)	2400.00		
6	Corrosion inhibitor pump A/B	2400.00		
7	PMCS panel - controller and cards	856.80	Intermediate	5384.40
8	WHCP/HPU pump	750.00		
9	LED escape lightings	744.00		
10	DEG battery charger (UCP panel)	633.60		
11	PMCS panel-transmitters	528.00		
12	Telecom equipment 2	480.00		
13	Telecom equipment 3-network switch	480.00		
14	Switch-rack control and protection circuit	480.00		
15	SIS/FGS panel-transmitters	432.00		
16	PMCS panel-ultrasonic flow meter	360.00	Low	2055.80
17	SIS/FGS panel-beacon	300.00		
18	SIS/FGS panel-F&G detectors	264.00		
19	Solar battery charger	256.80		
20	PMCS panel-solenoid valves	240.00		
21	SIS/FGS panel-solenoid valves	240.00		
22	Telecom equipment (VHF–FM Base station)	195.00		
23	PMCS panel–HMI	100.00		
24	Racon	72.00		
25	SIS/FGS panel-linear heat sensing cables	28.00		
Total				24480.20

Table 8: Different models of SWTs and their specifications (SD3DEX datasheet, 2006) (Kingspan Wind, 2013) (Zephyr Corporation, 2011) (JCE Energy, 2016)

	SWT1	SWT2	SWT3	SWT4
Rated power (kW)	3	2.5	1	1.05
Rotor diameter (m)	3.9	3.8	1.8	1.7
Cut in speed (m/s)	2.5	3.5	2.5	3.0
Cut out speed (m/s)	None-continuous operation			
Certification	ATEX	ATEX	Not explosion proof buy it is currently used in Malaysia	ATEX IECEx

longest diameter while SWT4 has the smallest diameter. A longer diameter corresponds to a greater rotor swept area which means more power can be extracted from the wind given that the cut-in speed is exceeded. As there is no cut-out speed for the SWTs, they will rotate and generate power continuously as long as the cut-in speeds are satisfied, unless the amount of power generated reaches the rated power.

Figure 2 shows the power generated by different models of SWT at different wind speeds. The power curves of different SWTs are indicated by different colours as stated in the legend. A wind turbine will start to generate power only after the cut-in speed is exceeded by the wind, the cut-in speed of each SWT is denoted as v_c in the figure. It can be seen that, SWT1 generated the highest power at different speeds as it has the lowest cut-in speed which is 2.5 m/s and also the largest swept area. Similarly, SWT2 generated slightly lower power as compared to SWT1 as its swept area and turbine radius are a little smaller than the SWT1's. As SWT3 and SWT4 have rotor radius which are a lot smaller than the one's of SWT1 and SWT2, the power generated by them were a lot lower than the power generated by SWT1 and SWT2. SWT1 and SWT3 started to generate power after the wind speed exceeded 2.5 m/s while SWT2 and SWT4 generated zero power until the wind surpassed 3.5 m/s and 3 m/s respectively which are their cut-in speed. As there is no cut out speed for the SWTs, after their cut-in speed were satisfied, the power generated increased as wind speed increased until their rated power were reached. The maximum amount of power that can be produced by SWT1, SWT2, SWT3 and SWT4 are 3000W, 2500W, 1000W and 1050W respectively. In conclusion, among all of the selected wind turbines, SWT1 is able to generate the highest amount of power at any wind speed, followed by SWT2, SWT3 and SWT4.

The average wind speeds of the ten identified locations from January to December for the past 3 years, 2017 to 2019 were obtained from (World Weather Online, 2019). The data from 2017 to 2019 for each location was combined into just 1 year by calculating the average values for these 3 years, as recorded in Table 9.

The average wind speeds throughout 12 months (2017-2019) for the ten different locations were plotted in Figure 3. This was done in order to analyse the trend of wind throughout a year at different locations and also to identify the locations that are feasible to harness wind power via SWTs.

Figure 2: Power curves of different SWTs at different wind speeds

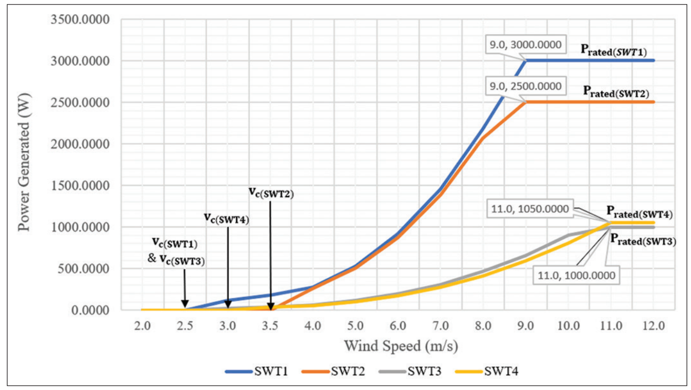


Figure 3: Comparison of the trend of wind speeds from January to December (2017-2019) at different locations

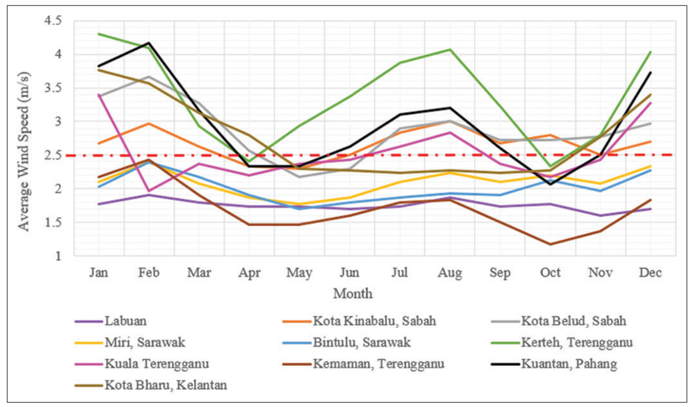


Table 8 stated that the lowest possible cut-in speed for the selected models of SWT that can be installed on offshore platforms in Malaysia is 2.5 m/s. Referring to Figure 3, it can be seen that, the average wind speed for every month throughout a year in Kemaman, Labuan, Bintulu and Miri were lower than 2.5 m/s. Hence, these locations do not have the potential to harness wind power via SWTs.

There are two monsoons, in other words, wind seasons in Malaysia-Northeast Monsoon and Southwest Monsoon. The Northeast Monsoon happens from mid-October to the end of March while the Southwest Monsoon hits during late May to September. The Northeast Monsoon which is also called the east coast monsoon of the peninsular Malaysia hits the eastern side of the peninsular-Kelantan, Terengganu and Pahang. Hence, it can be seen that the wind speeds in Kerteh (green line), Kuantan (black line), Kota Bharu (light brown line), and Kuala Terengganu (pink line) escalated in the mid-October and their wind speeds remained above 3 m/s until the mid-March or the end of March, except for Kuala Terengganu. The wind speeds in Kota Bharu and Kuala Terengganu stopped rising and started to drop since January as they are located at the top of the east coast of peninsular hence, they are less affected compared to the other towns/cities. While during the Southwest Monsoon (late May to September) that is coming from the southwest direction of Malaysia, is also called the west coast monsoon that affects the western part of the peninsular. However, the effect on the western part of the peninsular-Perlis, Kedah. Penang, Perak, Selangor, Kuala Lumpur, Putrajaya, Negeri Sembilan, Melaka and Johor were not noticeable as the wind was be blocked by Indonesia which is located right below the west coast of the peninsular. Although the wind was coming from the southwest direction, it would still 'pass by' the east coast of peninsular and the top of the east Malaysia-Sabah. Therefore, the wind speeds in these places gradually increased from May to September. Although there is no wind that hit directly on the east Malaysia-Sabah, Labuan and Sarawak, the wind speeds in Sabah remained average throughout the year as it is located at the top of Borneo and the wind would "pass by" in either direction. The wind speeds in Sarawak and Labuan were low and it is not suitable to explore the wind energy in these two areas as they are located at the bottom part of the Borneo and the impact of wind is relatively weak.

The locations where offshore O&G platforms are normally located which have the potential for wind power are Kerteh (green line), Kuantan (black line), Kota Bharu (light brown line), Kota Belud (grey line), Kota Kinabalu (orange line) and Kuala Terengganu (pink line). Among all these locations, Kerteh has the highest average wind speed and Kuala Terengganu has the lowest wind speed throughout 12 months.

Table 10 shows the updated locations that have the potential to apply SWT for power generation on offshore O&G platforms and their average wind speeds throughout 12 months (2017 to 2019). There are six locations in total that are viable for power generation on offshore platforms via SWTs.

The power generated by different models of SWTs at different locations from January to February were calculated by using the rotor swept areas, the average wind speeds and the average air densities (Haponiuk, 2019) taken from year 2017 to 2019 (average values). Figures 4-9 shows the power generation of different models of SWTs at the six locations from January to February (2017 to 2019) at the recorded average wind speeds. Note that, power generation starts only after the cut-in speed of wind turbine is exceeded.

Figure 4 shows the power generated by different models of SWTs at Kota Kinabalu, Sabah under the average wind speeds from January to February (2017–2019). Apparently, in April, May, June and November, none of the SWTs was able to extract power from the wind as the average wind speeds in these months were around 2.0 to 2.5 m/s which did not exceed the cut in speeds of all the SWTs. For the other months, only SWT1 and SWT3 generated power, where SWT3 generated lower power than SWT1 due to its smaller rotor swept area. SWT2 and SWT4 were not able to generate any power in Kota Kinabalu throughout the year as the highest average wind speed from January to December was only 3.0 m/s where the cut in speed of both of the SWTs were not exceeded. In August, the highest average wind speed from January to December was reached at 3.0 m/s. The highest power throughout 12 months was extracted by SWT1 in August which was around 110W.

Figure 5 shows the power generated by different models of SWTs at Kota Belud, Sabah under the average wind speeds from January to February (2017-2019). All of the SWTs was not able to extract any power from the wind in May and June as the maximum average wind speed reached in these months was only 2.5 m/s which did not exceed the cut in speeds of all the SWTs. SWT1 and SWT3 were

Table 9: Average wind speeds at the identified locations from January to February (2017-2019) (World Weather Online, 2019)

	Average Wind Speeds from January to December (2017-2019) (m/s)											
	January	February	March	April	May	June	July	August	September	October	November	December
Labuan	1.77	1.90	1.80	1.73	1.73	1.70	1.73	1.87	1.73	1.77	1.60	1.70
Kota Kinabalu, Sabah	2.67	2.97	2.63	2.33	2.30	2.50	2.83	3.00	2.67	2.80	2.50	2.70
Kota Belud, Sabah	3.37	3.67	3.27	2.57	2.17	2.30	2.90	3.00	2.73	2.73	2.77	2.97
Miri, Sarawak	2.10	2.40	2.07	1.87	1.77	1.87	2.10	2.23	2.10	2.20	2.07	2.33
Bintulu, Sarawak	2.03	2.40	2.17	1.90	1.70	1.80	1.87	1.93	1.90	2.13	1.97	2.27
Kerteh, Terengganu	4.30	4.10	2.93	2.40	2.93	3.37	3.87	4.07	3.23	2.33	2.80	4.03
Kuala Terengganu, Terengganu	3.40	1.97	2.37	2.20	2.37	2.43	2.63	2.83	2.37	2.17	2.43	3.27
Kemaman, Terengganu	2.17	2.43	1.90	1.47	1.47	1.60	1.80	1.83	1.50	1.17	1.37	1.83
Kuantan, Pahang	3.83	4.17	3.17	2.33	2.33	2.63	3.10	3.20	2.60	2.07	2.50	3.73
Kota Bharu, Kelantan	3.77	3.57	3.13	2.80	2.30	2.27	2.23	2.27	2.23	2.27	2.77	3.40

Table 10: Offshore locations that are feasible to harness wind power via SWTs and their average wind speeds from January to December (2017-2019) (World Weather Online, 2019)

	Average wind speeds from January to December (2017-2019) (m/s)											
	January	February	March	April	May	June	July	August	September	October	November	December
Kota Kinabalu, Sabah	2.67	2.97	2.63	2.33	2.30	2.50	2.83	3.00	2.67	2.80	2.50	2.70
Kota Belud, Sabah	3.37	3.67	3.27	2.57	2.17	2.30	2.90	3.00	2.73	2.73	2.77	2.97
Kerteh, Terengganu	4.30	4.10	2.93	2.40	2.93	3.37	3.87	4.07	3.23	2.33	2.80	4.03
Kuala Terengganu, Terengganu	3.40	1.97	2.37	2.20	2.37	2.43	2.63	2.83	2.37	2.17	2.43	3.27
Kuantan, Pahang	3.83	4.17	3.17	2.33	2.33	2.63	3.10	3.20	2.60	2.07	2.50	3.73
Kota Bharu, Kelantan	3.77	3.57	3.13	2.80	2.30	2.27	2.23	2.27	2.23	2.27	2.77	3.40

Figure 4: Power generated by different SWTs at Kota Kinabalu, Sabah under the wind speed from January to February (2017-2019)

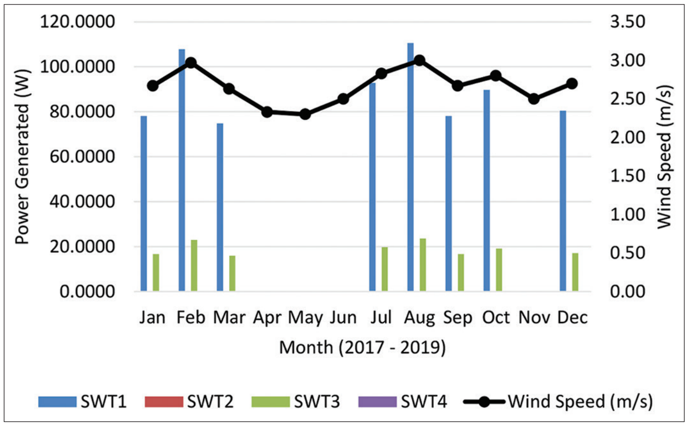


Figure 5: Power generated by different SWTs at Kota Belud, Sabah under the wind speed from January to February (2017-2019)

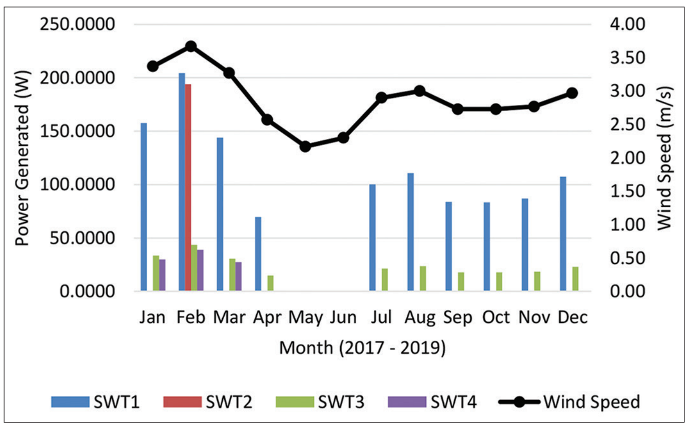
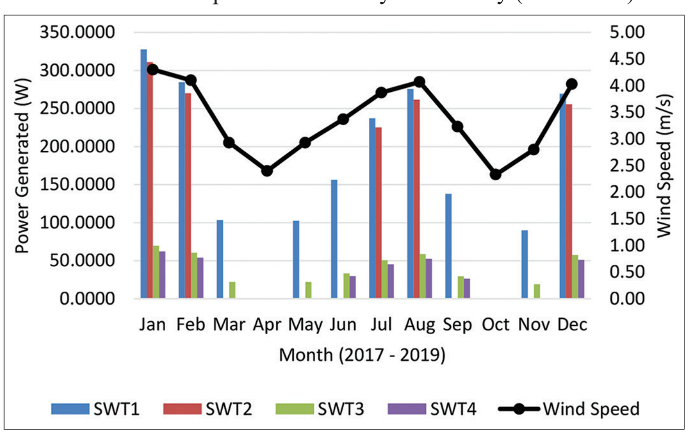


Figure 6: Power generated by different SWTs at Kerteh, Terengganu under the wind speed from January to February (2017-2019)



capable to extract power in all the other months except for May and June. SWT2 was only able to extract wind power in February as it requires the highest cut-in speed among (3.5 m/s) all of the SWTs and it generated a relatively high level of power compared SWT3 and SWT4 due to its large rotor sweep area. SWT4 was only able to generate power in January, February and March as it has a high cut in speed which is 3.0 m/s and the power generated was low on average due to its small sweep area. All of the SWTs extracted their maximum power from the wind in February which

Figure 7: Power generated by different SWTs at Kuala Terengganu, Terengganu under the wind speed from January to February (2017-2019)

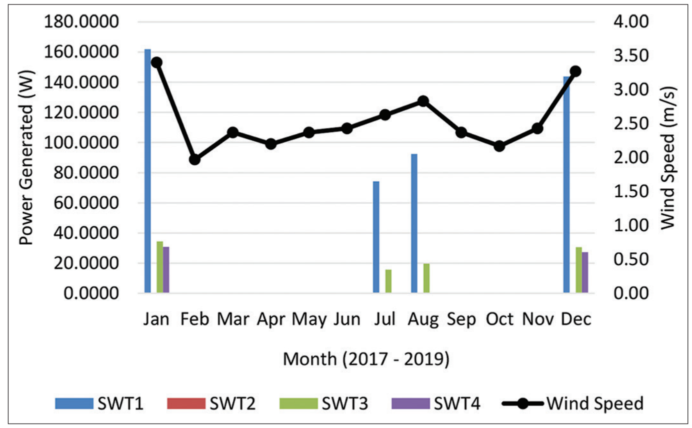


Figure 8: Power generated by different SWTs at Kuantan, Pahang under the wind speed from January to February (2017-2019)

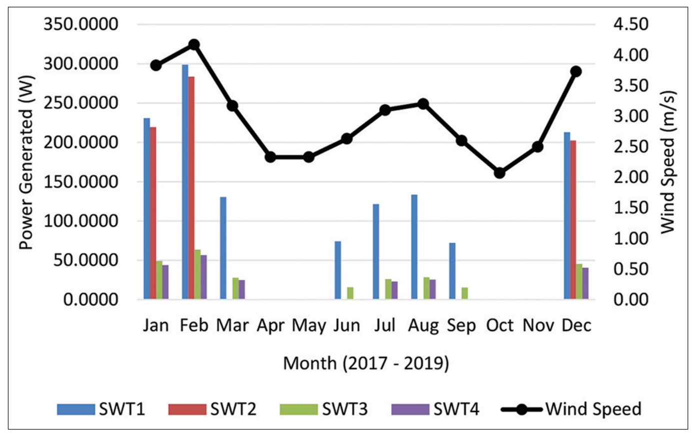
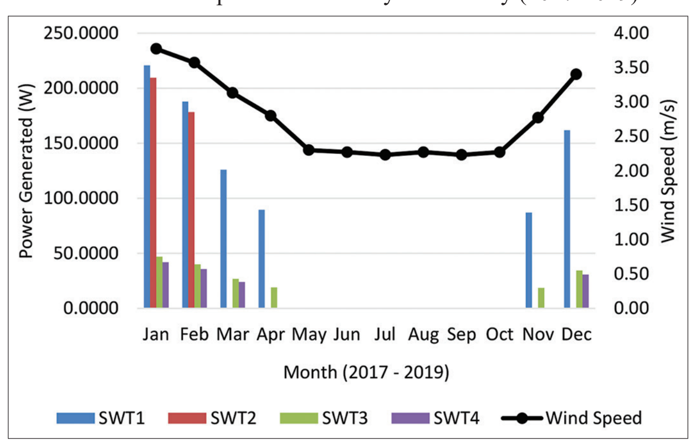


Figure 9: Power generated by different SWTs at Kota Bharu, Kelantan under the wind speed from January to February (2017-2019)



had an average wind speed of 3.67 m/s. In February, the maximum power throughout 12 months was extracted by SWT1 at more than 200W. SWT2 generated the second highest power in February which was slightly below 200W.

Figure 6 shows the power generated by different models of SWTs at Kerteh, Terengganu under the average wind speeds from January to February (2017-2019). The wind speeds in April and October were lower than 2.5 m/s hence no SWTs were able to generate power in these months. Similarly, SWT1 and SWT3 were able to generate power for all the months except for April and October. SWT2 generated power only in January, February, July, August and December. The power generated was high in general but was still lower than that of SWT1's. SWT4 worked in every month except for March, April, May, October and November. Among all of the SWTs, it generated the lowest level of power throughout the year due to its smallest rotor sweep area. The highest power was extracted from the wind in January by SWT1 at more than 300W as the wind speed exceeded 4.0 m/s.

Figure 7 shows the power generated by different models of SWTs at Kuala Terengganu, Terengganu under the average wind speeds from January to February (2017-2019). The wind speeds from February to June and September to November did not exceed 2.5 m/s, hence zero power was produced throughout these months. SWT1 and SWT3 were able to generate power for all of the months except for the months mentioned just now. SWT2 cannot be used in Kuala Terengganu as the highest wind speed throughout 12 months was only 3.4 m/s which is lower than its cut in speed. SWT4 only managed to generate power in January and December. The highest power generated was in January by SWT1 which was around 160W.

Figure 8 shows the power generated by different models of SWTs at Kuantan, Pahang under the average wind speeds from January to February (2017–2019). The wind speeds in April to May and October to November did not exceed 2.5 m/s, hence there was no power generation occurred in these months. SWT1 and SWT3 were able to generate power for all the months except for the months that the wind speeds did not exceed 2.5 m/s. SWT2 generated power only in January, February, and December. The power generated was only slightly lower than that of SWT1's as they have similar rotor sweep area. SWT4 worked only in the months that had average wind speeds higher than 3.0 m/s which were January to March, August to September, and December. Similarly, it generated the lowest level of power throughout every month due to its smallest rotor sweep area. The highest power was extracted from the wind in February by SWT1 at almost 300W.

Figure 9 shows the power generated by different models of SWTs at Kota Bharu, Kelantan under the average wind speeds from January to February (2017-2019). There was no power extracted from the wind by any of the SWTs from May to October as the average wind speeds in these months were <2.5 m/s. Similarly, SWT1 and SWT3 were able to generate power for all the months except for the months having wind speeds below 2.5 m/s. SWT2 generated power only in January and February as the average wind speed exceeded 3.5 m/s. SWT4 worked only from January to March and December. Similarly, compared to the other SWTs, it generated the least power in every single month due to its limitation of rotor swept area. The highest power was extracted from the wind in January by SWT1 at almost 300W.

The energy consumed per annum by each category of equipment was calculated and recorded in Table 11. As the equipment under the category 'High' are high power machineries, its annual energy consumption was the highest among the three categories, followed by "Intermediate" and "Low." The values of the annual energy consumption were used to calculate the percentage that could be supplied by different SWTs at different locations to each category as shown in Table 12. Referring to Table 12, on an offshore platform at Kota Kinabalu, SWT1 could either supplied 13.41% of the annual energy consumption of category "High" or 73.55% of the annual energy consumption of category "Intermediate" or 192.63% of the annual energy consumption of category "Low" at a time. For the percentage that was more than 100%, it means that the SWT was able to generate more than the amount of power that was required by that category of equipment per year.

To better visualize the percentages recorded in Table 12, a stacked bar chart was constructed as shown in Figure 10.

From Figure 10, it is apparent that, among all of the SWT, SWT1 is able to supply the highest amount energy for the annual energy consumption on a typical offshore platform at any of the six offshore locations in Malaysia. This is then followed by SWT2, SWT3 and SWT4 with the exception of a few locations which are Kota Kinabalu, Kota Belud, and Kuala Terengganu.

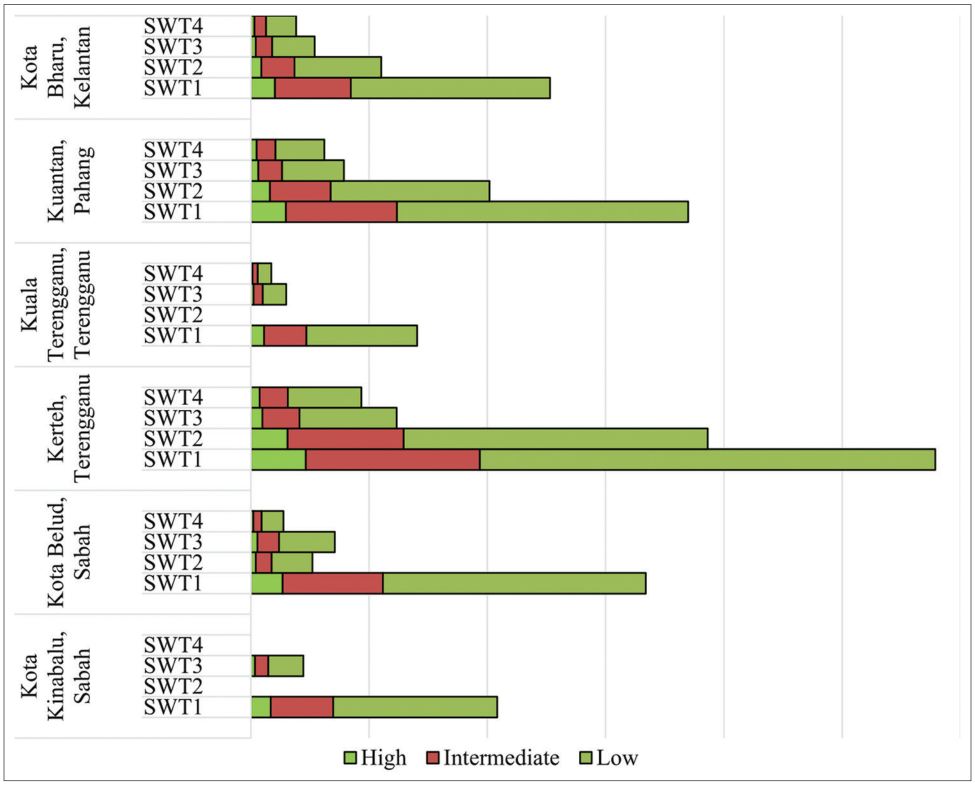
Table 11: Total annual energy consumption of different categories of equipment

Category of equipment	Total daily energy consumption (Wh/day)	Total annual energy consumption (Wh/annum)
High	17040.00	6219600
Intermediate	5384.40	1965306
Low	2055.80	750367

Table 12: Percentage of annual energy consumption of each category of equipment that could be supplied by different SWTs at different locations

Kota Kinabalu, Sabah				
Category	SWT1 (%)	SWT2 (%)	SWT3 (%)	SWT4 (%)
High	8.37	0.00	1.78	0.00
Intermediate	26.48	0.00	5.64	0.00
Low	69.35	0.00	14.77	0.00
Kota Belud, Sabah				
High	13.41	2.10	2.86	1.11
Intermediate	42.43	6.63	9.04	3.50
Low	111.12	17.37	23.67	9.16
Kerteh, Terengganu				
High	23.24	15.51	4.95	3.75
Intermediate	73.55	49.08	15.67	11.87
Low	192.63	128.56	41.03	31.09
Kuala Terengganu, Terengganu				
High	5.65	0.00	1.20	0.69
Intermediate	17.88	0.00	3.81	2.20
Low	46.84	0.00	9.98	5.76
Kuantan, Pahang				
High	14.85	8.11	3.16	2.50
Intermediate	46.98	25.65	10.01	7.91
Low	123.05	67.18	26.21	20.72
Kota Bharu, Kelantan				
High	10.15	4.43	2.16	1.54
Intermediate	32.14	14.02	6.85	4.88
Low	84.17	36.73	17.93	12.77

Figure 10: Visualization of the percentage of annual energy consumption of each category of equipment that could be supplied by different SWTs at different locations



In Kota Kinabalu, SWT2 and SWT4 would not be able to generate any electrical power as the average wind speed in Kota Kinabalu is low and the cut in speeds of both of the SWTs are not satisfied. Hence, SWT1 and SWT3 are the only choices and SWT1 generates higher power than SWT3. In Kota Belud, SWT1 generated the highest percentage of the energy consumed by each category of equipment per year on an offshore platform, followed by SWT3, SWT2 and SWT4, as SWT2 requires higher cut in speed than SWT2 and the wind speed in Kota Belud was not as high as the other locations. In Kuala Terengganu, the similar order implies except that SWT2 cannot be used here as the average wind speed in Kuala Terengganu would not exceed its cut in speed which is 3.5 m/s.

Among the three categories of equipment, the total annual energy consumption of the low power consumption equipment – category "Low" will be fulfilled the most, followed by category "Intermediate" and category "High." Among the six offshore locations with wind power potential, the most amount of wind power can be harnessed at Kerteh while Kuala Terengganu has the weakest wind power potential.

7. CONCLUSION

The need of replacing fossil fuels on offshore O&G platforms with renewable energy sources is encouraged as an effort in fighting climate change. Harnessing wind power by installing small wind turbines (SWTs) on the platform is a good alternative as their installations occupy lesser space as compared to solar panels. By combining a storage bank with the wind energy source, a smooth and stable supply can be guaranteed despite the unpredictable weather conditions. However, it is recommended to use a hybrid system that integrates more than one sources together such as solar panels and wind turbines due to the active lightning activity in Malaysia that might strikes the wind turbine and destroy the electronic parts. The application of hybrid system that involves wind as one of the energy sources is better than installing only solar panels as the installation of SWTs help to save up spaces.

The research was conducted in order to determine the viability of SWTs on offshore platforms at different locations of Malaysia. SWT requires a certain amount of speed in order for it to be able to function properly. According to the research conducted, not every area in Malaysia is suitable for SWT application. The areas that are suitable for SWTs are Kota Kinabalu (Sabah), Kota Belud (Sabah), Kerteh (Terengganu), Kuala Terengganu (Terengganu), Kuantan (Pahang) and Kota Bharu (Kelantan). These areas experience relatively even wind speed throughout the year averaging about eight to 10 months of possible wind collections, and SWT can generate electricity for, with the exception of Kuala Terengganu and Kota Bharu where wind collections are only possible for 4 and 6 months respectively. The places that are not suitable for SWT such as Labuan (Federal Territory of Malaysia), Bintulu (Sarawak), Miri (Sarawak) and Kemaman (Terengganu) are determined to be not feasible to harness wind power via SWTs as the wind speeds throughout the year in these places were lower than the minimum cut-in speed among the four selected models of SWTs which is 2.5 m/s.

Due to the amount of relatively high wind speed throughout the year, Kerteh (Terengganu) is discovered to be the most suitable for SWT generation on offshore O&G platforms. However, places like Kuala Terengganu, experienced 8 months of unsuitable wind speed. Although offshore platforms at Kuala Terengganu may collect enough wind to generate electricity, but due to the number of months that experience very little wind speeds, it would not be a good investment to install SWTs at Kuala Terengganu. Therefore, we concluded that, among the locations that have the potential for SWT generation, Kuala Terengganu is the least suitable location.

Last but not least, among the selected models of SWTs, SWT1 that has lowest cut-in speed and largest swept area offers the highest power generation per annum on offshore platforms at different locations. At the end of the project, the use of SWT1 at Kerteh is suggested at it can power up to on average of either 23.24% of high-power machinery or 73.55% of medium power machinery or 192.63% of low power machinery. This project has shown that, the implementation of SWT is a feasible solution for power generation for a certain category of equipment on offshore O&G platforms in Malaysia if the platforms are installed at areas that have high wind speeds throughout the year.

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