Evaluation of offshore marine current energy performance in Malaysia

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Abstract. Venturi Marine Current Energy Device (VMCED) is a current energy converter, which is focused in this research that aimed to harness the continuous movement of ocean current. It focuses on the venturi effect to increase the efficiency of the flow velocity in resulting higher output energy from the ocean current. This research aimed to identify the best potential location of Malaysian waters to deploy the device. A computational fluid dynamic analysis was conducted in this study considering two important parameters i.e. velocity and differential pressure in the VMCED. These parameters were adopted in the analysis to measure the highest velocity and pressure differential. Among of the locations in Malaysia analysed in this study, it is to conclude that VMCED is best to be deployed in Straits of Malacca. This location measured the highest velocity and differential pressure of ocean current compared to others.

1. Introduction
Fossil fuels are the main energy resources formed from decayed plants and animal fossils, which exist in the core of the earth for over millions of years. This was not considered as a sustainable energy due to its characteristics of depletion over years due to over-consumption of the supply. Meanwhile it took long process to form and resupply. However, it is the main sources of non-renewable energy universally consumed by human. More than 30 billion tons of carbon dioxide (CO₂) are released due to fossil fuel burning each year. This is an amount that considerably exceeds the level that can be recycled by nature. In consequence, the excess CO₂ remains in the environment for a long time, which affects the air quality and gradually increase the world temperature that resulted in the climate change [1]. This phenomenon causing the nature to evolve, which to an extent the ice block in the Artic melts and thus the ocean level keeps rising constantly and precipitation is expanding. The situation of natural catastrophes brings a huge impact to the animals and human [2].

Due to continuous environmental issues, studies agreed that a transition to a sustainable energy supply is compulsory. This is to protect and control the supply of energy for the next generations [3]. The exploitation of non-renewable energy was discovered in the last few centuries but was considerably more efficient [4]. Nevertheless, shifting to renewable energy supply is necessary. In addition, increasing concern about environmental problems due to the shortage of non-renewable energy and rising costs of fossil fuels have promoted a growing interest in massive integration of renewable energy sources in power systems [5]. There are various types of renewable energy sources available globally
e.g. solar, biomass, wave, current, tidal etc. In this study, the analysis was only limited to the current energy converters owing that the current velocity in Malaysia still considerably acceptable.

In order to harness energy from ocean currents in Malaysian waters, a thorough study is required first to assess the potential to deploy Marine Current Energy Devices (MCEDs). Areas in Malaysia were identified based on the potential of the velocity current flow are One Fathom Bank, Raleigh Shoal, Tanjung Segenting and Pulau Tioman. Even though highest current velocity measured for these areas are 1.3 m/s, yet the velocity is not satisfactory for economical and efficient energy extraction [6]. Therefore, in this study the concept and performance of the Venturi Marine Current Energy Device (VMCED), which allows an increment on velocity of the incoming flow at the venturi area was proposed and the performance of VMCED in Malaysia water was also investigated.

2. Renewable energy

For the last few decades, the utilization of renewable energy systems for daily applications were expanding due to the endless issues of arising global temperature alteration and environmental contamination [7]. Renewable energy technologies are sustainable power sources, which naturally replenished and optimal utilization of these resources will reduce the ecological footprint based on present and future commercial together with the societal demand. In fact, these sources of energy are only contributing 14% of the total world energy demand as of now [8]. Surprisingly, renewable energy is becoming the world’s most evolving source of energy globally with 3.0% consumption increasing per year. On top of that, the renewable share of total energy use increases from 10% in 2008 to 14% in 2015 in the reference case [9]. Renewable energy is a potential resource in supplying energy [10]. In addition, renewable energy will continuously replenish and most likely remained as it is. There are various types of renewable energy such as solar, wind, geothermal heat, tidal, waves, ocean current, biomass etc. These resources are readily available to be harvested and may cause less environmental footprint [11].

2.1. Marine renewable energy

Marine renewable energy is a source of power system located at the ocean which represent an infinite and robust vitality resources. Generally, marine energy can be harnessed in the form of ocean current, tidal, ocean thermal energy, ocean wave and salinity gradient. The amount of ocean energy is enough to supply the global energy demand [12]. Henceforth, marine energy industry is growing throughout the years. Yet, it is still in the beginning of progression with some of the prototypes are undergoing testing period to prove its capability. High levelized cost of energy (LCOE) is corresponding to the progression of the marine renewable technology, compared to other traditional energy sources.

The oceans provide boundless offshore renewable energy to the world but the technologies invention to extract the energy systems of the seas still at an early stage of development [13]. The evidence of marine renewable energy effectiveness has been proved which it has been estimated that both, the ocean current power stations and tidal power plant could generate up to several 100 terawatt-hours of electricity supply per year worldwide [14]. In addition, the efficiency of renewable technologies constructed in any specific marine project not only influenced by the performance of the technology but also by the cost of necessary maintenance expenditure, operation and installation to maintain the project [15].

2.2 Ocean current as a renewable energy

Generally, ocean currents are large scale of cross sections. Ocean currents is highly potential to be developed as a potential future sustainable power source. It provides a consistent and predictable energy, which make it as an efficient energy supply. However, the exploration and development of the ocean currents energy are relatively still expensive and need detail study on the technical part. Nevertheless, renewable energy sector had become a demanding supply source since the tragic catastrophe of nuclear power plant at Fukushima in 2011 [16]. Ocean current power contained high load capacity, which is generated from the movement of seawater inside the deep ocean with less
variability compare to another renewable energy sources such as wave, wind and solar. It has enormous potential to accommodate cost-effective electrical power generation globally [17]. The ocean currents are supplying a relatively constant current energy with the hydrokinetic devices. As well the technology is rather like energy extraction such as wind energy [18].

The tidal motions and sea circulation are the main principle of ocean current generation. However, there are other sources that may affect the currents flow such as temperature variation of the ocean and the salinity levels. Different approach and design innovation can be utilized to harness the long-lasting kinetic energy exist within the marine streams. The nature of ocean currents is like the wind energy, where the power accessible at a specific site is corresponding to the liquid density and its velocity. The only big difference between both energy resources is the density of the working fluid. As the seawater has approximately 832 times greater density than the air so the output energy of ocean currents would be more efficient and substantially more when comparing both resources [19].

3. Data Collection and analysis
The data of this study was retrieved from the Malaysian authorities. These data were further analysed and incorporated with the previous findings for the determination of potential location for the deployment of VMCED in Malaysia.

3.1. Concept of venturi marine current energy device (VMCED)
VMCED operated based on the venturi concept. Venturi concept was discovered by physicist named Giovanni Battista Venturi in 1797. The fundamental concept of venturi is the dynamic pressure of the fluid or liquid that reach its peak when flowing inside the throat section. On top of that, as the velocity of the substance increase in the throat, the area will be having lowest static pressure [20]. A venturi tube is composed of a contraction section, throat section and diffusion section. Figure 1 shows the illustration of the venturi device and the sections. The fluid that flows through the narrow throat section will accelerate and followed by a pressure drop in that specific area. This natural phenomenon which accelerate the fluid and decrease the pressure point is called as venturi effect [21].

![Figure 1. Illustration of venturi’s section.](image)

VMCED is designed based on the venturi effect, which consist of a funnel-like shape inlet connected to a narrow throat section. Figure 2 shows the design of VMCED. This design is believing to be able to concentrate the flow of current passing through the turbine inside the throat section, and able to release high current flow. The turbine can be potentially driven by the advantage of high velocity current flow inside the throat section and the induced pressure differential inside the system [22]. Conceptually, the VMCED is designed to be laid on the seabed to harness the ocean current movement. Thus, a hypothesis can be constructed as the higher the velocity of ocean current, the higher the energy produce by the device. To ensure the velocity of ocean current is high, the determination of location will be crucial as it will affect its energy result. The technologies and capabilities developed for the tidal and ocean current device keep growing and the full potential of the devices can be achieved in the future [23].
3.2. Potential Location for VMCED in Malaysia
This study aimed to identify the potential location to deploy VMCED in Malaysia by examining the marine current speed of the location. Four targeted locations, which distributed in west coast, east coast and south coast of Malaysia were identified. Table 1 listed the targeted locations along with the marine current velocity.

Table 1. Average of marine current velocity at various locations.

| Locations                  | Region               | Range of Average Marine Current Velocity (m/s) |
|----------------------------|----------------------|-----------------------------------------------|
| One Fathom Bank, Selangor  | West Coast Malaysia  | 1.02 – 1.18                                   |
| Raleigh Shoal, Melaka      | West Coast Malaysia  | 0.93 – 1.13                                   |
| Tanjung Segenting, Johor   | South Coast Malaysia | 0.85 – 1.03                                   |
| Pulau Tioman, Pahang       | East Coast Malaysia  | 0.51 – 0.59                                   |

Figure 2. Design of venturi marine current energy device (VMCED).

Figure 3. Area of potential location in Malaysia map.
Based on data collected from desktop study, it is concluded that One Fathom Bank in Selangor at the Straits of Malacca measures the highest ocean current velocity, 2.3 knots [6], [24]–[26]. Following with that is the Off Raleigh Shoal, which measured the maximum average marine current speed of 2.2 knots. Tanjung Segenting measured the third highest current velocity of 2.0 knots. Lastly, Kampung Teluk Salang, Pulau Tioman measured the current velocity of 1.14 knots. Based on the desktop study, it was concluded that the VMCED is suitable to be deployed in One Fathom Bank.

3.3 Hydro-kinematics performance of VMced

Hydro-kinematics performance of the VMCED was simulated and measured by computational fluid dynamics method. Modelling, simulation and analysis of the flow motion in the VMCED was performed respectively. The model was simulating the environmental conditions as of Malaysian ocean current based on the four possible locations. The flow of processing the simulation is followed in phases to avoid any error in achieving high quality result. The density of seawater was set as a constant of 1025 kg/m³. Since, the power coefficient is in the range between 0.3 to 0.45, hence this study has adopted the average value of 0.4.

3.4 Modelling and Meshing.

The concept of VMCED was modelled and meshed as shown in figure 4. The model was designed to be in 2D rectangular mesh structure with 4387 elements, to investigate the fluid flow inside the device. Next, the model size and input of environmental criteria were remained constant throughout the simulations. The VMCED model generally comprised of inlet, throat and outlet section. The boundary condition was defined by introducing a rectangular area. The fore and back of the rectangular was defined as inflow and outflow. During the simulation, the current was generated into the VMCED model through the inlet and compressed through the throats. The performance of the VMCED was measured and evaluated as the current flow into the structure.

![Figure 4. Mesh model of VMCED](image)

4. Result and discussion

4.1 Computation of the power output

The power output of the VMCED were numerically analysed based on the four targeted locations. Table 2 listed the current velocities measured at inlet, throat and outlet section of the VMCED for all the locations. As a whole, it could be validated that the throat section was successfully increased the current velocity, whereby One Fathom Bank generally yield the greatest velocity of 2.625 m/s.
Table 2. Velocity of ocean current at each location.

| Location             | V, Velocity at Throat Section (m/s) | ρ, Density of Fluid (kg/m^3) | Cp, Power Coefficient | P, Generated Power Output |
|----------------------|------------------------------------|-----------------------------|-----------------------|--------------------------|
| One Fathom Bank      | 2.625                              | 1025                        | 0.400                 | 3708.018                 |
| Off Raleigh Shoal    | 2.483                              | 1025                        | 0.400                 | 3138.225                 |
| Tg Segenting         | 2.251                              | 1025                        | 0.400                 | 2338.193                 |
| Pulau Tioman         | 1.302                              | 1025                        | 0.400                 | 452.467                  |

Table 3. Generated power output at each location.

| Location             | Velocity (m/s) | Velocity at Throat Section (m/s) | Outlet |
|----------------------|----------------|---------------------------------|--------|
| One Fathom Bank      | Inlet          | 2.625                           | 1.640  |
| Off Raleigh Shoal    | 1.130          | 2.483                           | 1.622  |
| Tg Segenting         | 1.030          | 2.251                           | 1.403  |
| Pulau Tioman         | 0.590          | 1.302                           | 0.834  |

Figure 5 shows the current velocity measured at the throat section as function of time for the VMCED for all the locations. The graph shows that typically in between 20 to 30 seconds the marine current accelerates instantly, as the fluid moves toward the throat section. It is again measured that One Fathom Bank gives the highest velocity.

Figure 5. Velocity versus time.

To maximize the power output of the device, turbine was assumed to be installed in the throat section. Hence, the energy generated can be harnessed efficiently. Higher velocity of the flow into the device may results highest output of generated power. It is also hypothesizes that higher velocity may produce higher power output. Henceforth, from the analysis it could be observed that power output from One Fathom Bank location resulted 3708.018 W/m^2.

VMCED works generally under the principle of Bernoulli’s and Continuity equation. Velocity and pressure are the main parameters to be observed in this research. Hence, aside from velocity, a huge difference of pressure from the inlet and the throat section could drive the turbine to rotate faster than...
the other locations. Basically, the pressure in the throat section will fall drastically inside the throat section. It is conceptually proven that One Fathom Bank is the most suitable location to employ the VMCED due to the velocity and pressure occurrence at the throat section. Therefore, it is hypothesis that the larger the differential pressure between the inlet and the throat section, the higher the effectiveness of the device. Result findings in figure 6 that shows the pressure in time and Table 4 that illustrated the VMCEC pressure at all the locations, validated the statement. One Fathom Bank measured the greatest differential pressure between the inlet and throat section, which given as 749 pascal and -2372 pascal, respectively.

![Figure 6. Pressure versus time.](image)

**Table 4. Pressure of the sections measured for all locations.**

| Location           | Inlet  | Throat Section | Outlet |
|--------------------|--------|----------------|--------|
| One Fathom Bank    | 749.0  | -2372          | 0.102  |
| Off Raleigh Shoal  | 731.0  | -2273          | -0.112 |
| Tg Segenting       | 539.0  | -1788          | -7.410 |
| Pulau Tioman       | 187.5  | -575           | -13.00 |

5. **Conclusions**
Oceans have the highest potential in supplying sustainable energy either for the community or to industry with its vast availability that cover 70% of the world surface. Estimation was done by researchers that 0.1% of the total ocean energy extracted is enough to fulfil the world energy demand. Venturi Marine Current Energy Device (VMCED) was focused in this study to pursue in harvesting the current energy and the potential location for the deployment was identified at the west coast. In this study, venturi effect on the VMCED was found to be able to increase the efficiency by more than 100% of current velocity and differential pressure compared to conventional MCED which shown the comparison in between the inlet and throat section of the system. Amongst the four locations studied, One Fathom Bank has the greatest potential in which it could achieve 2.625 m/s of current speed compared to other location which is higher than the south coast and east coast of Malaysian waters.
While for future research, it is recommended that this research can be further in details to indicate the suitability, maintenance and the cost-effective to employ the VMCED in Malaysian waters.

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