Estimation of Sea Current Energy Potential by Using Calculation Models of Horizontal Axis Current Turbine in Toyapakeh Strait, Nusa Penida, Bali

Estimasi Potensi Energi Arus Laut Dengan Menggunakan Perhitungan Model Turbine Arus Poros Horizontal di Selat Toyapakeh, Nusa Penida, Bali

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ABSTRACT: Toyapakeh Strait has a fairly strong ocean current velocity with a velocity between 0.5 m/s – 3.2 m/s. The duration of the strong current (V> 0.5 m/s) ranges from 13-22 hours per day. The location of the strong current occurrence is located to the east of Nusa Lembongan Island, precisely at the stationary current measurement location. Vertical distribution of the direction and velocity currents at this location are not uniform from the top to the bottom, especially in the water column depths of 2 m, 4 m and 6 m, whereas at the water column depths of 8 m to 16 m are relatively uniform. Calculation results of potential electrical power by using the horizontal axis turbine model with a capacity of 35.9 kW (Rite Verdan), 100 kW (Tocardo DD702HT) and 250 kW (Tocardo DD1001HT) show that all of the values have the optimal electric powers, especially during the spring tide, whereas during the neap tide only the turbine with a capacity of 35.9 kW can retrieved an optimal electrical power. Calculation result of the electric power potential by using the method of calculation performed by the Electric Power Research Institute Inc. at the point of measurement, indicated that the total amount of energy 42.5 MWh per month for the turbine model Tocardo DD1001HT, 17.27 MWh per month for turbine model DD702HT Tocardo, and 9.08 MWh per month for the turbine model Rite Verdan.

Keywords: Toyapakeh Strait, current velocity, time duration, electric power, depth of the water column

ABSTRAK: *Perairan Selat Toyapakeh mempunyai kecepatan arus laut yang cukup kuat dengan kecepatan berkisar antara 0,5 m/det – 3,2 m/det. Durasi terjadinya arus kuat (V>0,5 m/det) berkisar 13 – 22 jam per hari. Lokasi tempat terjadinya arus kuat terletak di sebelah timur Pulau Nusa Lembongan, tepatnya di lokasi tempat pengukuran arus stasioner. Secara vertikal distribusi arah dan kecepatan arus di lokasi ini tidak seragam dari atas ke bawah, terutama pada kedalaman kolom air 2 m, 4 m dan 6 m, sedangkan untuk kedalaman kolom air 8 m sampai 16 m relatif seragam. Hasil perhitungan potensi daya listrik dengan menggunakan model turbin sumbu horisontal dengan kapasitas 35,9 kW (Rite Verdan), 100 kW (Tocardo DD702HT) dan 250 kW (Tocardo DD1001HT) diperoleh daya listrik yang cukup optimal terutama saat spring tide, sedangkan saat neap tide hanya turbin dengan kapasitas 35,9 kW yang masih menghasilkan daya listrik secara optimal. Hasil perhitungan potensi daya listrik dengan menggunakan metode perhitungan yang digunakan oleh Electric Power Research Institute Inc. di titik pengukuran diperoleh total energi yang dihasilkan dari model turbin Tocardo DD1001HT adalah sebesar 42,5 MWh per bulan, model turbin Tocardo DD702HT adalah sebesar 17,27 MWh per bulan, dan model turbin Rite Verdan adalah sebesar 9,08 MWh per bulan.*

Kata Kunci : *Selat Toyapakeh, kecepatan arus, durasi waktu, daya listrik, kedalaman kolom air*

INTRODUCTION

Toyapakeh Strait is a part of the Lombok Strait. This strait is flanked by three islands, in the northern part flanked by Nusa Penida and Nusa Lembongan islands, and in the southern part flanked by Nusa Penida and Nusa Ceningan islands (Yuningsih et al., 2008) (Figure 1).

Based on the sea current measurement result, the dynamics of the movement of water masses in the strait was directly related to the movement of water masses in the Lombok Strait (Arief, 1992 in Utami, 2008). The movement of water masses was influenced dominantly by tidal current flow from Bali Sea in the north to Indian Ocean in the south. These water masses flow through Lombok Strait and resulted strong currents, especially
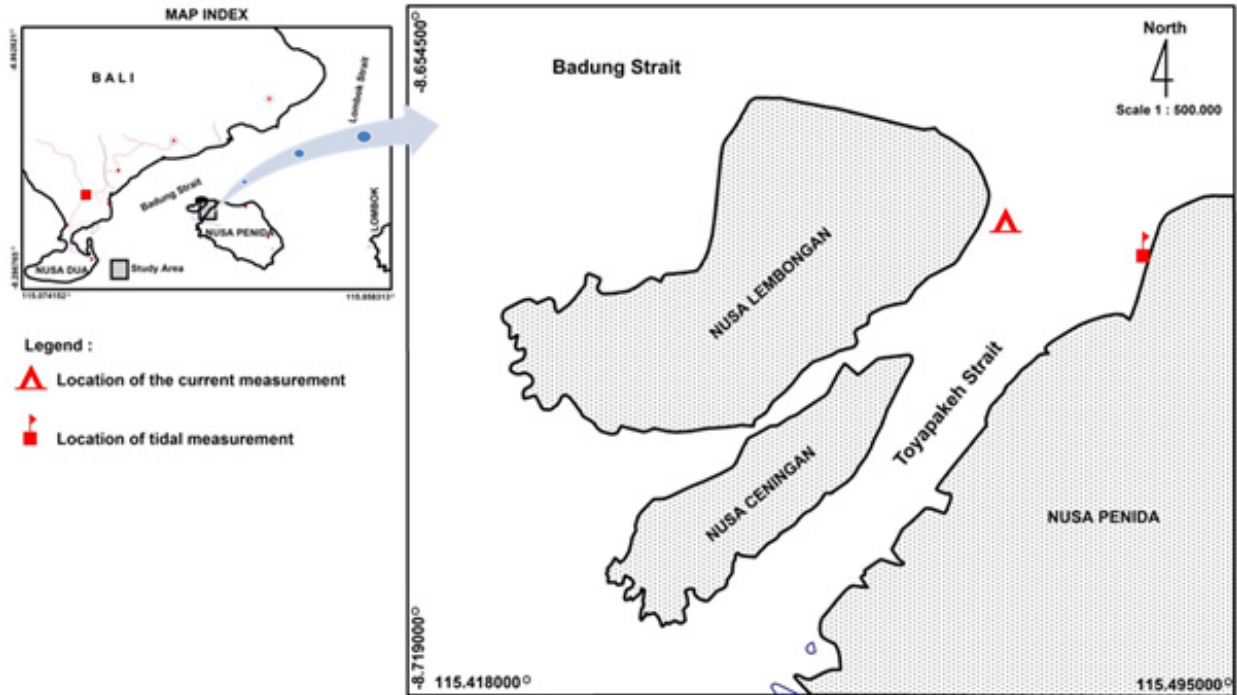

Figure 1. Map of study area (Yuningsih et al, 2008)

Based on the geological Map of Bali Sheet (Darman, 2012) the study area regionally composed of alluvium, with its constituent lithologies consist of gravel, sand, silt and clay, as the sediment of rivers, lakes, and beaches. In general, the age of the alluvium is Late Holocene. Nusa Penida, Lembongan and Ceningan islands are an archipelago located in the southeast of the island of Bali. These three islands are composed of limestone, local white and soft dolomite. In the southern part of Nusa Penida island, found the formation of weathered bedding limestone (Figure 2). Morphology of the limestone is a karst formed, which is characterized by the landsform of this island. The limestone has suffered erosion and weathering, shaping hills covered by meadows and dry fields, and only on the trail incisions of dry river and cliffs rather steep covered by a variety of vegetation. This morphology type can be seen from the top of Mundi Hill towards the south and west. The reef limestones unit of Late Pliocene in age are also widespread found in the south of Bali island, and known as the South Formation.

when the water movement through a narrow strait such as the Toyapakeh Strait.

According to the success stories in application of sea current electric power plant, in several location of strong currents velocity has been widely used for generating electric power from ocean current, such as in the Strait of Messina, Italy, the Strait of Strangford Lough in Northern Ireland and the Strait Uldolomok in South Korea (O'Rouke et al., 2010).

Besides having a strong current velocity, application of current power generator in strait water area also must comply with certain technical criteria in order to adjust a proper or model of the ocean current power plant. The criteria that should include in the consideration are uniformity of the vertical current velocity distribution, the time duration of strong current velocity that should be long enough time (15-20 hours/day), the depth of the sea should be not too deep, the morphology of the seabed should be relatively flat or gently sloping, protected from the influence of the sea waves directly, should not too far from shore (<1 km),
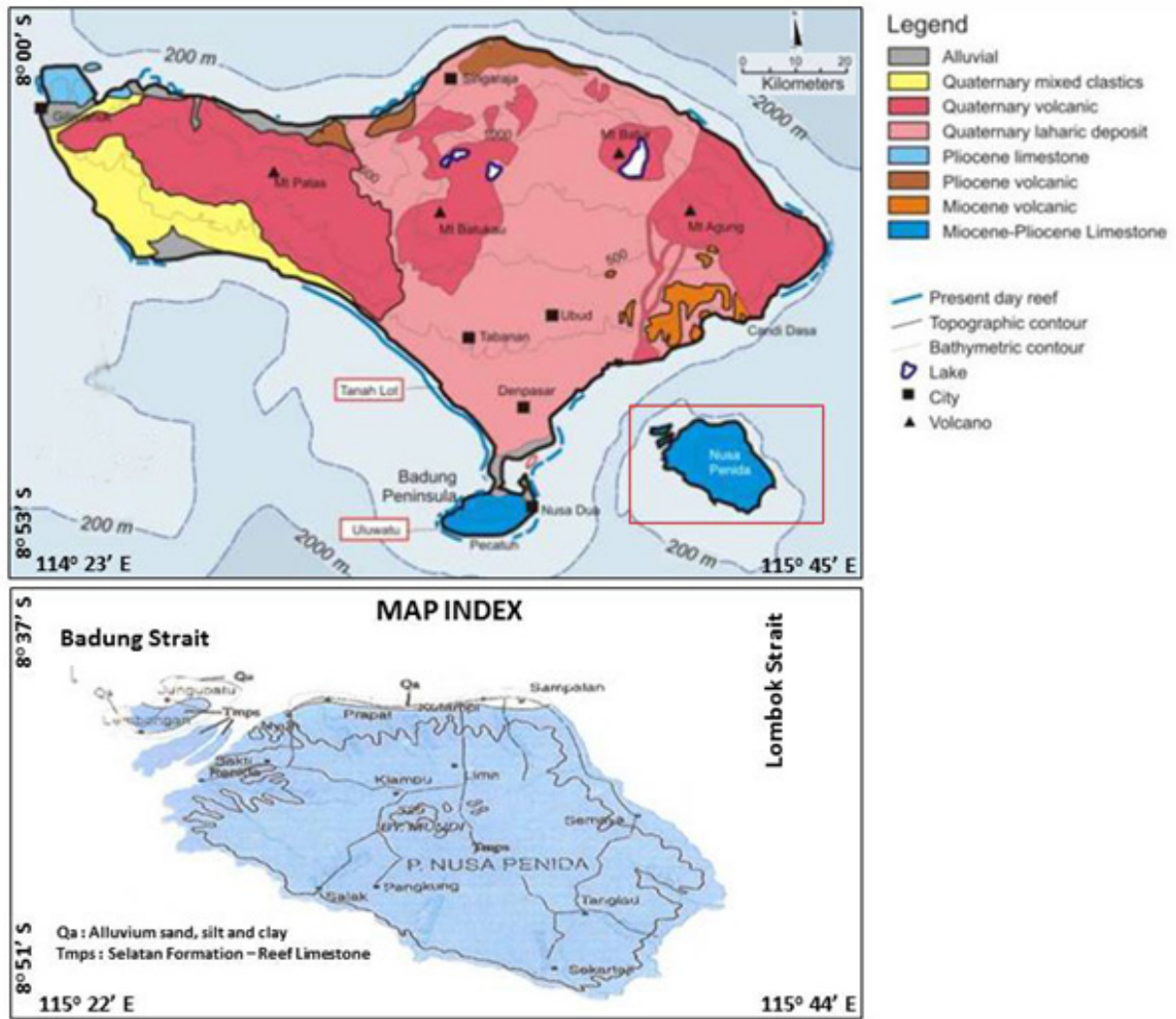
Figure 2. Geological map of the Bali (Simplified after Hadiwidjojo et al, 1998 and Darman, 2012)

close to the electricity grid, and the location should not across the cruise line of ships (Thake, 2005).

Some technologies of turbine power from ocean current has been developed in the world (Bedard et. al, 2005), but in general there are classified only two models of turbines, i.e. turbines with horizontal axis and vertical axis turbines (Fraenkel, 2002). Both of these turbine models have advantages and disadvantages in converting the ocean current energy into electric energy (Anderson et al., 2011).

The objective of this study is to calculate the energy potential of ocean current that can be converted into electrical power by using three models of horizontal axis turbines. The calculation result will be used to select the proper model for implementation of current power plant in the Toyapakeh Strait.

METHODS

Ocean currents measurement in the Toyapakeh Strait was carried out in 2008 by using the stationary measurement method with an ADCP (Acoustic Doppler Current Profiler), Nortek equipment. Nortek ADCP was deployed at 21 m water depth and was located at the northeastern of Nusa Lembongan island precisely at the position coordinates of 115° 28'29,47'E; 8° 40' 30''S. Current data was recorded at the interval time of every 15 minutes during long period of measurement for 10 days, started from April 4 to 13, 2008. The data obtained are the *in situ* vertical distribution of velocity and direction of ocean currents. These water column measurements were set up at every 2 m intervals, so the equipment were recorded the speed and direction of sea current at every water column depths (D) of 18 m, 16 m, 14 m, 12 m, 10 m, 8 m, 6 m, 4 m, and 2 m. Measurement of currents in situ was performed coincided with the tidal measurement. Measurements of tide were

conducted for 15 days from April 4 to 19, 2008 with recording data interval of 15 minutes. The equipment used was a Piel Scale and an Automatic Valeport Tide Gauge which were deployed in the Nusa Penida jetty at the coordinates of 115°29'13,82"E; 8°40'36"S. Integrated tidal and ocean current data were correlated to analyze the relationship between the dynamics of ocean currents and the character of tide. Estimation of electric power generated from ocean current energy conversion is calculated by using specific turbine model which indicated by the following equation (Fraenkel, 1999):

$$P = 1/2 \, \rho \, A \, |V|^3 \, \eta$$

P = power generated (kW)
ρ = density of sea water (1,025 kg/m^3)
V = current velocity (m/sec)
A = blade surface area (m^2)
η = coefficient for turbines (%)

Furthermore, to calculate the amount of the monthly electric power generated by the turbine it is considered to use the calculations performed by the Electric Power Research Institute Inc. (Bedard, et al., 2005) which applying a model of horizontal axis turbine. Turbine model used is a model Tocardo DD702HT, Tocardo DD1001HT and Rite Verdan. DD702HT Tocardo turbine model has a rotor diameter of 6.3 m, cut-in speed of 0.4 m/s, the turbine efficiency is 33% with a capacity of 100 kW (Tocardo International BV, 2014); DD1001HT Tocardo turbine model has a diameter of 9.9 m, cut-in speed of 0.4 m/s, the turbine efficiency is 33% with a capacity of 250 kW (Tocardo International BV, 2014); while Rite Verdan turbine model has a rotor diameter of 5 m, the cut-in speed of 0.7 m/s, 39.5% efficiency of turbine with a capacity of 35.9 kW (Bedard et al., 2005). In general, generator efficiency of the horizontal axis turbine model is approximately 95% (Bedard, et al., 2005).

RESULTS

Relationship Between Tidal and Current Pattern

Tidal type in Toyapakeh Strait is included into mixture and tends to semi diurnal type which is floods and ebbs occurred twice within 24 hours. The range between highest water level and lowest water level during the spring tide was 2.7 m, while during the neap tide was 1.25 m. Viewing the relationship between current velocity and tidal current pattern shows that the changes of current velocity are generally followed by the pattern of floods and ebbs. Vertical distribution of current velocities at the measurement point of every water column depths was relatively uniform, except at

the depth of 6 m water column. Current velocity at this water column was lower than other during the spring tide and the neap tide (Figures 3 and 4). It is suggested that of 6 m depth is probably the boundary or transition between upper (2 m and 4 m) and lower water columns (8 m, 10 m, 12 m, 14 m and 16 m). The current directions at the depth of the water column of 2 m, 4 m and 6 m are highly variable in both conditions at low tide and high tide conditions. It is estimated that the current velocity of every water column seems to be affected by external factors such as winds and waves, so this area includes the area of the turbulent current (Figure 5). While the other lower water column depths are seem to be not affected by external factors to the current pattern, so the direction of currents are relatively uniform patterns. During low tide to lowest tide conditions, the current direction tends to flow towards the east-southeast and it is turned towards southeast-east during high tide to highest tide conditions (Figure 6). If the current condition is considered to be the site location for ocean current turbine placement, the depth of the water column which is suitable for the placement of turbines is at the water column of 8 m to 16 m depth. Therefore, the turbine model that most suitable and appropriate to the characteristics of ocean currents in the Toyapakeh Strait is a typical of horizontal axis turbine model.

The strong current velocity occurred during low tide to high tide conditions, whereas the strongest current velocity occurred during the lowest tide. The strongest current velocity of 3.0 m/s – 3.2 m/s occurred during the spring tide, while at the neap tide of 1.7 m/s – 2.1 m/s, respectively. Furthermore, the current velocity tends to weaken significantly when the water flowed from high tide to highest tide conditions. The highest tide level was the weakest current velocity, which only ranges between 0.2 m/ s – 0.5 m/s.

Time Duration of Current Velocity

The time duration of current velocity were classified according to the current velocity (V) intervals, such as the current velocity of more than 0.5 m/s (V> 0.5 m/s) and smaller than 0.5 m/s (V<0.5 m/s). This classification is based on the assumption that a minimal current velocity that can drive the turbine (cut-in speed) is more than 0.5 m/sec. The duration of the current velocity for V> 0.5 m/s in Toyapakeh Strait ranges from 12.5 hours - 19 hours per day (Figure 7). The longest time duration occurred during spring tide condition was about 18.25 - 19 hours per day and the shortest time duration occurred during neap tide condition was about 12.5 – 14.75 hours per day. This picture shows that the time duration at the point of measurement location has a potential for construction
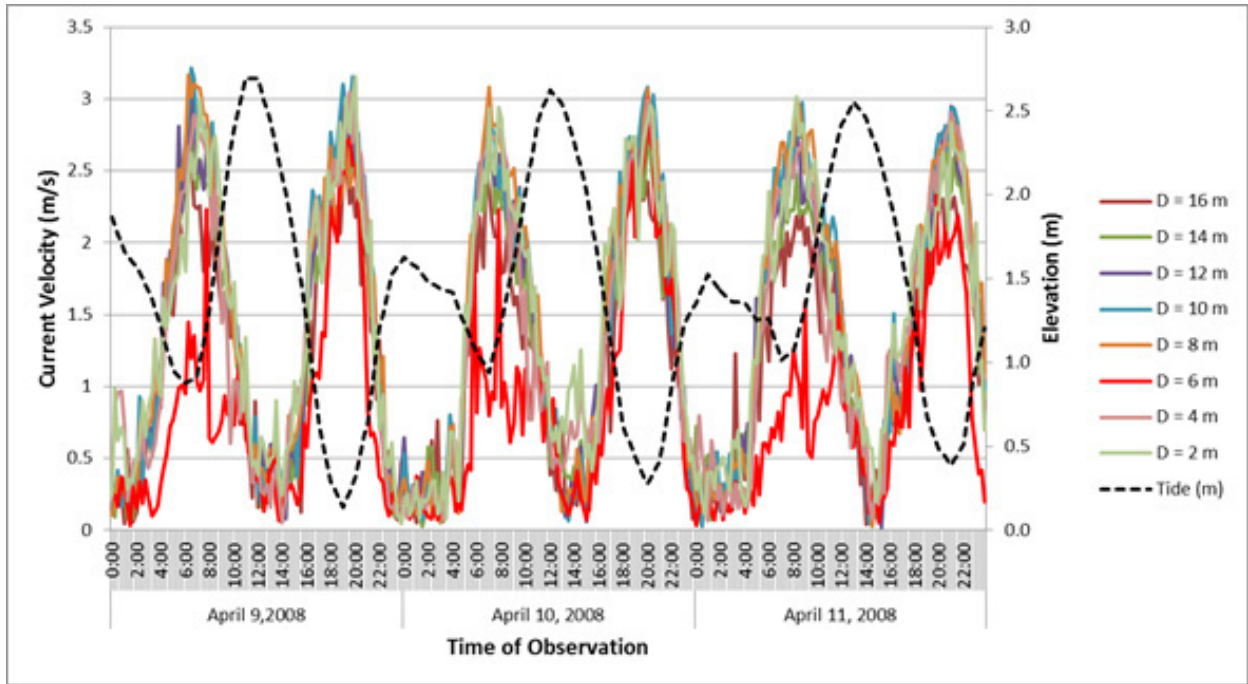
Figure 3. Distribution of vertical current velocity at every depth of water column during the spring tide, occurred on April 9 to 11, 2008.
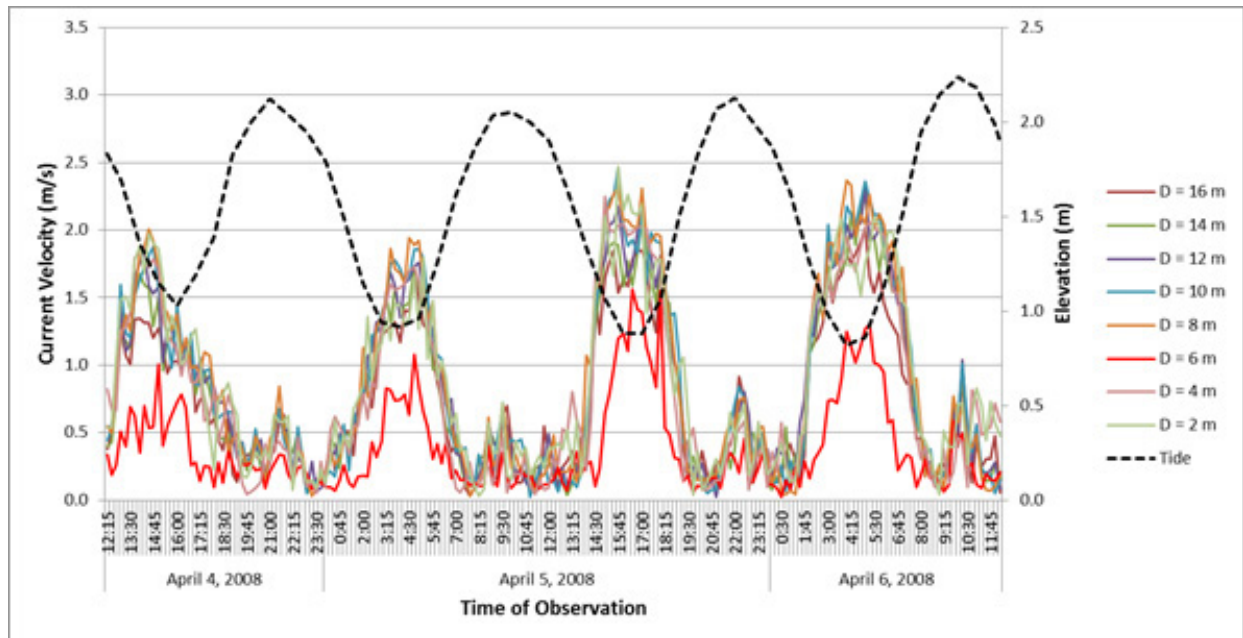

Figure 4. Distribution of vertical current velocity at every depth of water column during the neap tide occurred on April 4 to 6, 2008
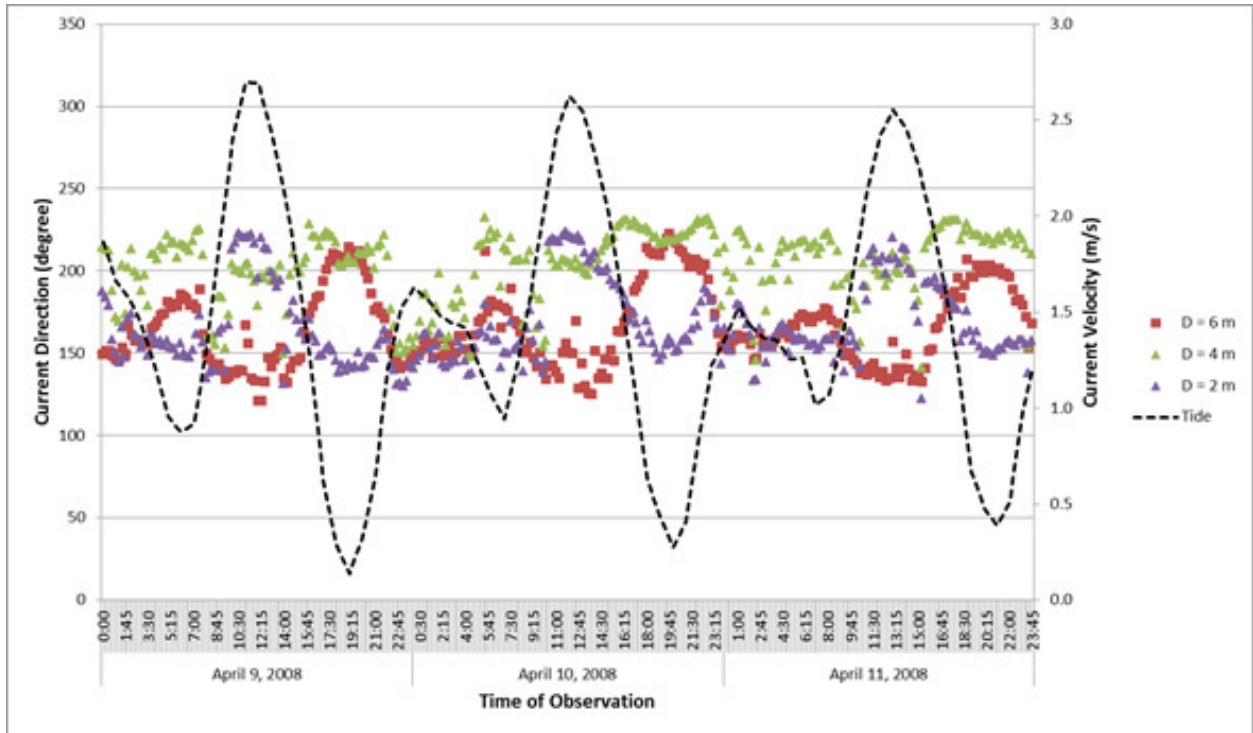
Figure 5.   Distribution of the current direction vertically of every depth of water column during spring tide at the depth of water columns of 2m, 4m and 6 m, on April 9 to 11, 2008.
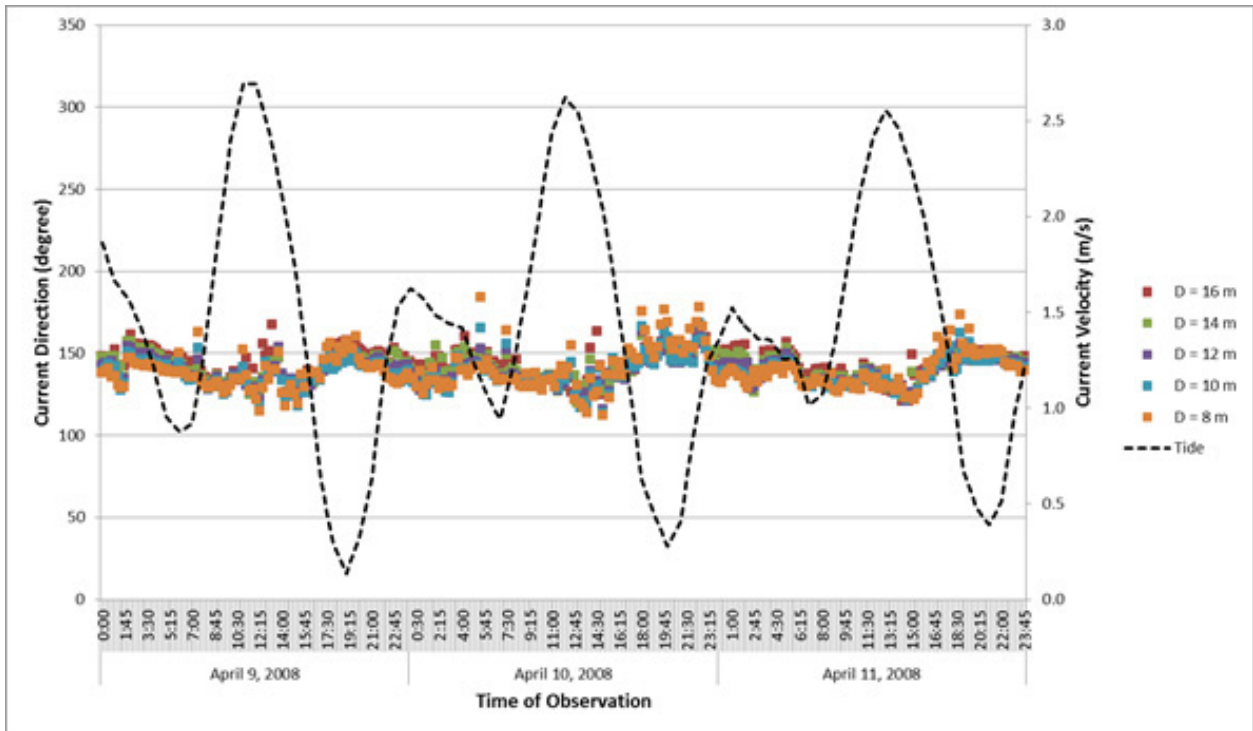

Figure 6.   Distribution of the current direction vertically of every depth of water column during spring tide at the water column depths of 8m, 10m, 12m, 14m and 16 m on April 9 to 11, 2008.
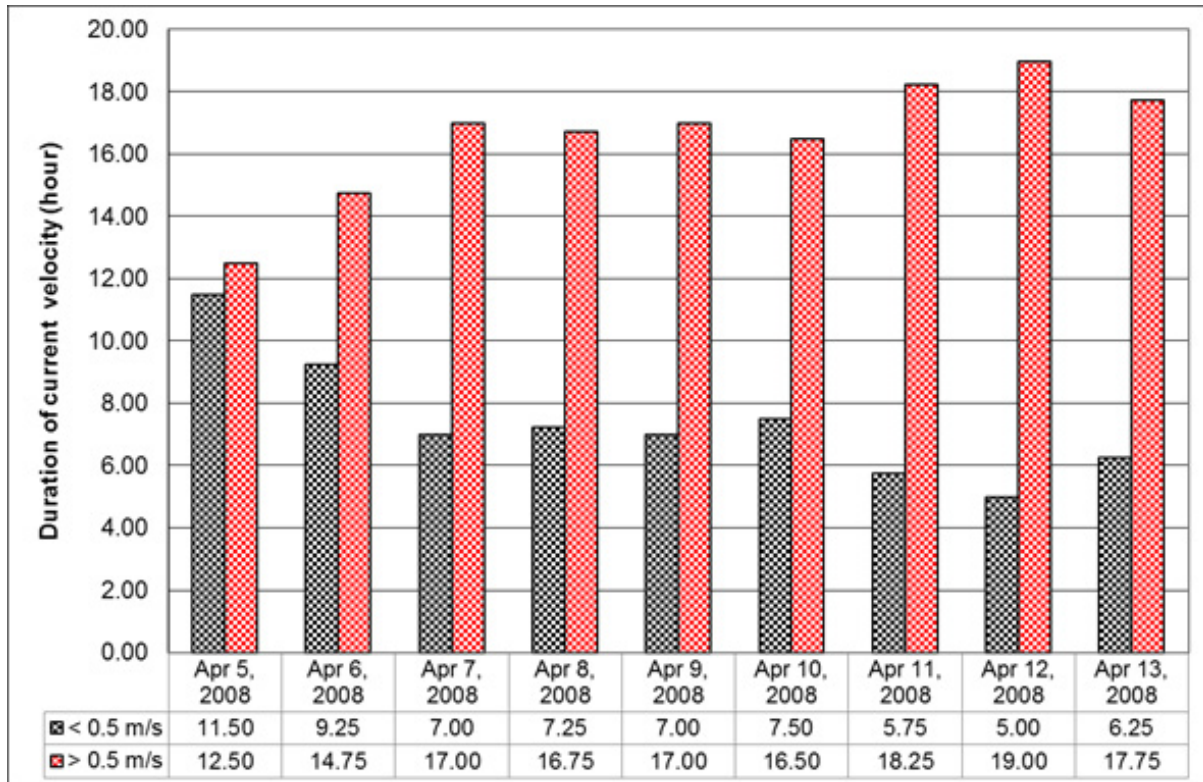
	Apr 5, 2008	Apr 6, 2008	Apr 7, 2008	Apr 8, 2008	Apr 9, 2008	Apr 10, 2008	Apr 11, 2008	Apr 12, 2008	Apr 13, 2008
< 0.5 m/s	11.50	9.25	7.00	7.25	7.00	7.50	5.75	5.00	6.25
> 0.5 m/s	12.50	14.75	17.00	16.75	17.00	16.50	18.25	19.00	17.75

Figure 7. The duration of current velocity in the Toyapakeh Strait, for cut in speed of V> 0.5 m/s and V<0.5 m/s.

of the current turbine power plants, especially for a turbine model which has a cut-in speed of 0.5 m/sec.

DISCUSSION

Calculation of electric power potential was carried out by using the prototype of horizontal axis turbine that mentioned above can be considered for selection site of current power plant position. The use of these models is to obtain a proper depth of turbine placement in accordance with the characteristics of ocean currents in the study area. Calculation results of the potential electrical power for every turbine model can be seen in **Figures 8 and 9.** During the spring tide, the third turbine model (Rite Verdan) will produce an optimal value of electric power (rated power). The output power for Tocardo DD1001HT turbine model, ranging from 5 kW-250 kW with time duration of 17-19 hours, and the full power of 250 kW can be achieved at the current velocity of 2.67 m/s. The output power for Tocardo DD702HT turbine model ranges from 5 kW - 100 kW with time duration of 17-19 hours, and the full power of 100 kW can be achieved at the current velocity of 2.67 m/s. The output power for Rite Verdan turbine model ranges from 5 kW – 35.9 kW with time duration of 17-19 hours, and the full power of 35.9 kW can be achieved at the current velocity of 2.08 m/s. Based on the calculation of current velocity data obtained on April 4-

13, 2008, during the neap tide condition, the turbines model Tocardo DD1001HT and DD702HT show that the electrical power results are less than optimal, while for the turbine model Rite Verdan shows that the electric power is a quite optimal. The calculation result for Tocardo DD1001HT turbine model shows that the power output ranging from 5 kW - 170 kW with time duration of 12.5 – 14.75 hours, so the optimal value of electric power of 250 kW has not reached. The output power calculation for Tocardo DD702HT turbine model duration of 12.5 – 14.75 hours shows that the electrical power of 35.9 kW can be achieved at the current velocity of 2.2 m/s.

Furthermore, to obtain the total value of the energy produced by each of turbine model, the total energy were calculated by using the method of calculation performed by the Electric Power Research Institute Inc. at the point of current measurement.

The calculation results are as follows:

- Total energy that can be generated by the turbine model Tocardo DD1001HT is approximately 42.53 MWh per month or 535.59 MWh per year.

- Total energy that can be generated by the turbine model Tocardo DD702HT is approximately 17.27 MWh per month or 217.48 MWh per year.

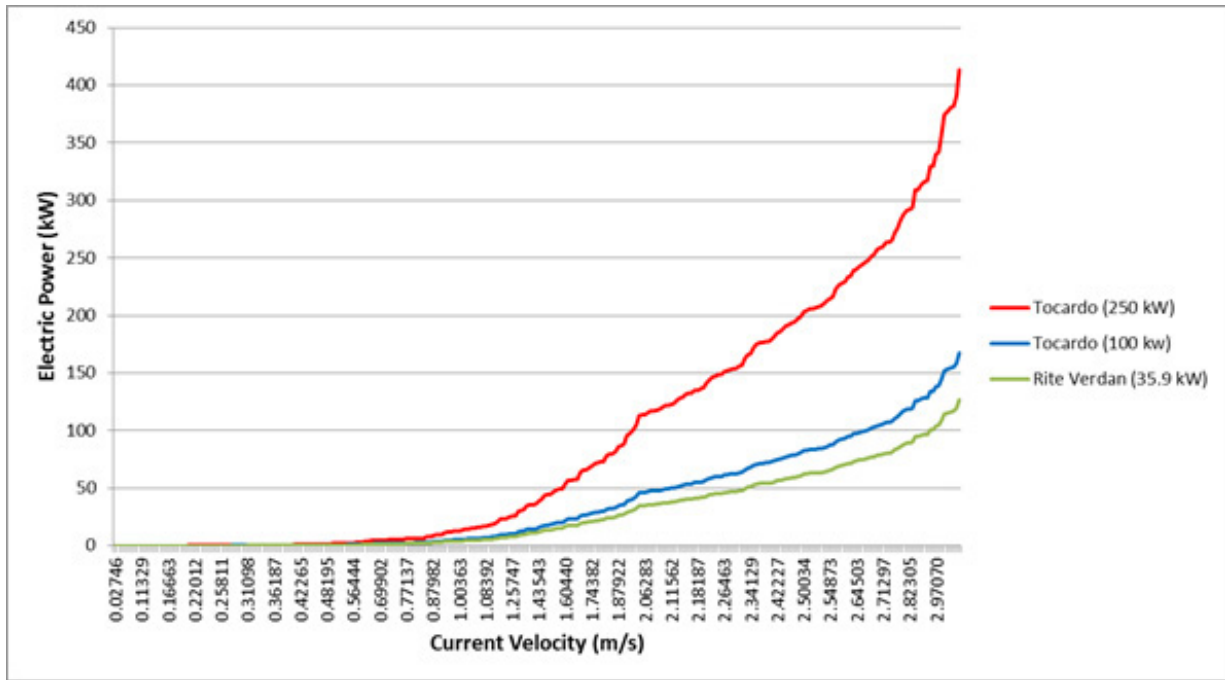- Total energy that can be generated by the turbine

Figure 8. The relationship between the current velocity and the electric power during the spring tide on 9th to 11th April, 2008 in the Toyapakeh Strait.
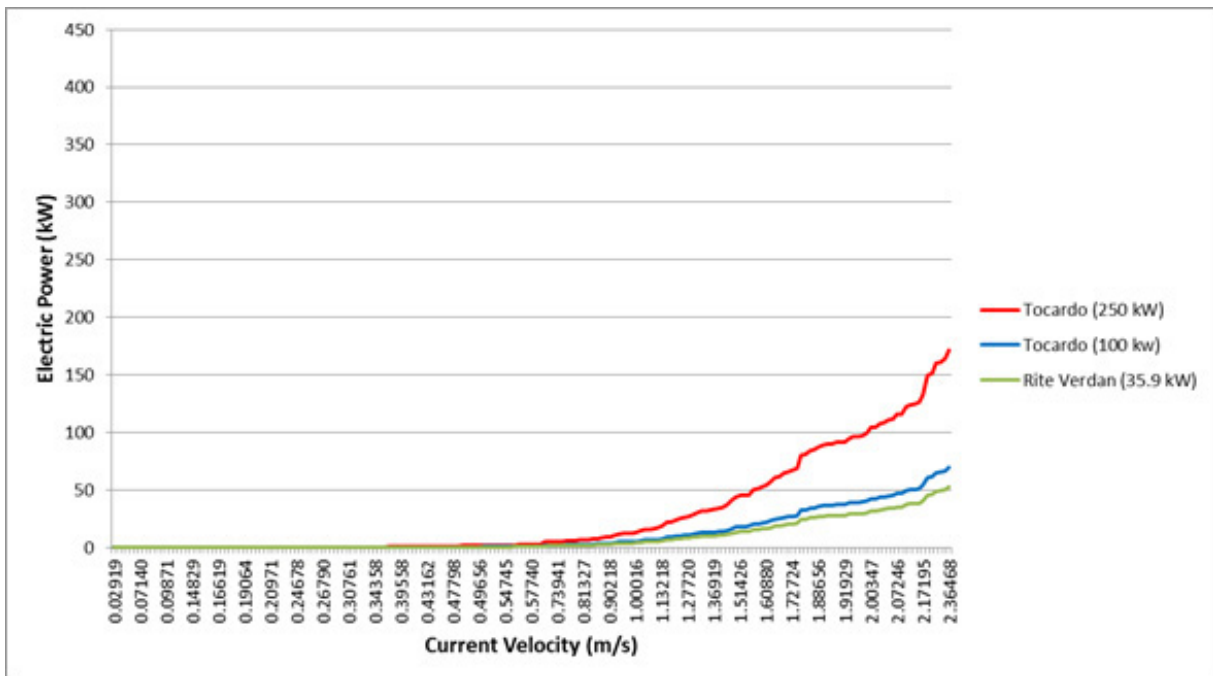

Figure 9. Relationship between the current velocity and the electric power during the neap tide on 4th to 6th April 2008 in the Toyapakeh Strait.

model Rite Verdan is 9.08 MWh per month or 108.55 MWh per year.

The comparison of calculation results show that the third turbine model Rite Verdan can generate an optimal electrical power due to the character of current velocity the Toyapakeh Strait.

In geological point of view and based on the basement rock of the seabed that comprises of massive limestone, it is hard enough to be the basement of the power plant foundation. In this case, there some difficulties if the power plant will be constructed in the floating barge or pontoon due to the disturbances of tidal ranges and current speeds which can reach more than 3.0 m/sec.

CONCLUSION

According to the results of this study, indicates that the turbine model that most suitable to the characteristics of ocean currents in the Toyapakeh Strait is a horizontal axis turbine model with capacity of 20 kW - 40 kW which has turbine rotor diameter of 5 m (Rite Verdan). The full power of 40 kW can be achieved during spring tide and neap tide when the current velocity ranges from 2.1 m/s – 2.2 m/s.

ACKNOWLEDGEMENT

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