

TIDAL ENERGY GENERATION USING THE DOUBLE-EMPTYING SYSTEM SCHEME

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Abstract. This paper presents the electrical power generation by using the tidal lagoon system. In general, using tidal concept, water will flow into the dam in one direction, and then water will be forced to be released back into the sea via the low-head one-way generator. In some cases, there is a two-way power generation where power is generated when water from the sea flowing into the dam and one more generation when power is released back into the sea via two different generators. However, in this paper, a new scheme of tidal generation namely Double-Emptying System is proposed where the power can be generated during in flow and out flow, but, by using just one low-head one-way turbine only. The operation of this scheme is explained in detail in the paper. Analysis regarding the potential power production is then executed on the best location in Malaysia; Port Klang. Findings show that by using the proposed technique, the maximum potential mean power can be generated in March whereas the minimum in June, with 9.8926 MW and 6.151 MW, respectively.

Keywords: tidal generation, tidal lagoon, double-emptying, renewable energy, without pumping.

1.0 Introduction

The trend of renewable energy has increases due to the growth in energy consumption and the raising awareness of global warming [1]. Nowadays, the issues of manipulating clean energy and the load demand management have been discussed actively around the world, particularly solar and wind energy. Each energy source has their advantage and disadvantage. For example, solar energy is clean and free, but, to convert the energy to electricity (using the photovoltaic modules); the cost is an obstacle.

In Malaysia, solar energy is promising, but since 1m² of PV module could cost up to RM20,000.00, it would be very expensive when compared to its conversion rate. In contrast with wind energy application in Malaysia, the purchasing cost is not the critical issue, but the wind resource is the main problem [2]. Therefore, discovering another potential renewable energy to overcome the problem of depletion of fossil fuel is very significant, particularly to sources that are available in Malaysia [1].

Another example is biomass where it was developed to be important application such as heat and power generation. Biomass also denoted as a clean renewable energy source that could be

obtained from the waste of natural and human activities. It is not includes from the organic material which has been transformed by the geological process into coal and petroleum. Biomass energy can be extracted from different sources such as wood, waste and alcohol fuel, algae, empty fruit branch, rice husk and others. Wood becomes a largest source comes from woods industry, agricultural and raw materials from the jungle. Second largest source is a waste comes from municipal solid and manufacturing waste and lastly alcohol fuel, which comes from the corn [3].

Besides solar, wind, and biomass energy, one of the new forms of renewable energy that has a positive potential in Malaysia is tidal power. This energy generation type may produce a sustainable energy resource. Even though tidal energy is not very popular in the world at this moment, it is technology, however, has been used since 1960s as proven by La Rance tidal power plant, France. [4]. It is actually was typically used for grinding grains into flour since tidal mills were invented in the early 1900s [5].

In the case of the tidal scheme, in the literature so far, it has been mentioned that there are a few methodologies in generating the electricity by using tidal generation. This can be classified into several types such as tidal stream, tidal barrage, tidal lagoon, and etc [6]. A tidal stream is a type that can generate energy from the speed of ocean current. This method will extract the speed of ocean current to turn turbines so that the electricity can be generated by extracting the mass of water or tides. The function of this tidal stream can be assumed as an underwater wind turbine or usually called as the tidal turbine [7].

For the second type of tidal generation which is known as the tidal barrage, it is depended on a basin to capture the energy from the water mass during going in and out of a river or bay due to tidal force [8]. Tidal barrage has the oldest technology compared to other tidal types. Even though barrage could produce some significant amount of energy, experience also show some drawback of it is system. The disadvantage of this system is barrage could change the physical system of a location. The placement of a barrage into an estuary may alter the flow of saltwater in and out of the estuary. This ultimately changed the hydrology and salinity, hence creating negative effects on the marine mammals that use the estuaries as their habitats. Barrage construction may also damage the flora and fauna, where during the construction, the estuary was isolated from sea water. For instance, as the consequences of La Rance's construction in France, some species lost their habitat. Furthermore, as a result of the barrage construction, sandbanks disappeared, such as experienced in the St. Servan beach where the sandbanks was badly damaged. The development of the barrage into the estuary also creating to the sediment accumulation problem, that was affecting the ecosystem and the operation of the barrage itself. This non-serve ecosystem then leading to fish killed. When the sluice gates are opened, fish may move safely, but when the sluice gates are closed, fish will try to swim out through the gates. In terms of capital cost, tidal barrage power schemes also have a high capital cost and a very low running cost [9].

Tidal lagoon is a new idea in order to exploit the energy from the differences tidal height to generate electricity. The structure is similar like a circular dam and was built on a seabed. Electricity will be generating when the tidal flow through the turbine into the impoundment when the tides rise and also flow out the impoundment when tides fall. So the electricity that will be generated is twice both at tide's rise and falls compared to the barrage. It also is not built fully across the estuary that will cause the negative effects on marine life like tidal barrages. Besides that by built the tidal lagoon, it will make the water through estuary flowing freely without any restrictions [10].

Therefore, in this work, tidal lagoon generation system will be considered since this energy source offers better advantages compared to the others. In addition, tidal lagoon is more practical to be applied in Malaysia due to the factor of its sea level and in terms of environment conservation. However, in this study, the tidal lagoon with the concept of double-emptying system will be considered. Hence, the objective of this paper is to present the principles of operation the double-emptying system, to calculate the generated power that can be produced by using this concept based on the most suitable location in Malaysia and analyse its potential of physical application. This paper is organized as follows: in section 2, the current situation of the tidal power scheme is presented while section 3 describes the working principle of the double-emptying system scheme. Section 4 shows experimental results and in section 5, some conclusions are given.

2.0 Overview of Tidal Power Scheme

Tidal power plant is not very popular to be built in the world. However, at some locations, this power plant has been proven working effectively; for instance, La Rance tidal power plant in France. The La Rance's power plant is the first and the largest tidal power plant installation built so far with an installed capacity of 240 MW. It was commercially operated since 1966 and now, this power plant still operating and working efficiently. At this power plant, 24 generators are being used, and each generator rated at 10 MW [11]. Other than La Rance, there are other examples of successful tidal power plants that have been built in the world. For example, Annapolis tidal power plant in Canada includes an installed capacity of 17.8 MW [12]. This plant has a larger turbine size compared to the La Rance plant [13]. Other plants were built at Kislaya Guba in Soviet Union and Jiangxia station in China. Each power plant installed capacity of 400 kW [14] and 3.2 MW [15], respectively, as shown in Table 1.

Table 1: Tidal Power Plant

| Site | Mean Tidal Range (m) | Basin Area (km ²) | Installed Capacity (MW) | Design Output (GWh/year) | In-Service Date or Status |
|----------------------------|----------------------|-------------------------------|-------------------------|--------------------------|-----------------------------|
| La Rance (France) | 8 | 17 | 240 | 540 | 1966 |
| Kislogubsk (Russia) | 2.4 | 2 | 0.4 | — | 1968 |
| Jiangxia (China) | 7.1 | 2 | 3.2 | 11 | 1980 (1 st unit) |
| Annapolis (Canada) | 6.4 | 6 | 20 | 50 | 1984 |

3.0 Double-Emptying System Scheme

In general, double-emptying system can be classified into two methods. The first method is called as double-emptying without pumping (DEW/OP), while another one called as the double-emptying double-pumping (DEDP). The former one is the topic that will be considered

in this study. According to Keith Dalton in [16], the double-emptying system could produce more power in 24 hours compared to the generation using the single-emptying system.

Since the floods and ebbs occur two times daily and consistently [17], this variable cannot be changed. So, as an alternative, to increase the energy production, two-ways direction of tidal generation is usually considered. Using this method, energy is generated when water is passing through the turbine A during the flood whereas the energy will be generated again when the water from the basin is released to the sea through the turbine B. Theoretically, this situation can be imagined where power can be generated two times by using two different generators.

To improve this generation scheme, a new arrangement was proposed where the two-way direction concept is used but the generation can be executed two times by using one-way low-head turbines. The illustration of this new arrangement is shown in Figure 1, where the structure is developed in the form of 'H'. From the figure, it can be seen that the proposed double-emptying system has a power house that is built in the cross bar and four sluice gates (Gate 1, Gate 2, Gate 3 and Gate 4). The generator is installed in the power house and has one-way direction. There are four valves that installed at all ends of the letter 'H' and these valves will control the operation time of the sluice gates.

During the flood (high tide), two valves (Gate 1 and Gate 4) will be wide opened for water entry and the others (Gate 2 and Gate 3) will be closed. The sea water will enter from the sea to the Basin 1 via Gate 1 and then passing through the low-head turbine that was installed in the power house before entering the Basin 2 and then the dam side via Gate 4. Using this concept, it can be seen that the turbine is rotating in one direction only. See the pathway with solid line to illustrate it is flow direction. This process will generate the electricity. During the ebbs (low tide), the Gate 3 and Gate 2 will be wide opened for the discharge process, and the others (Gate 1 and Gate 4) will be closed. At this time, the water will be going out from the dam/Basin 3 to the Basin 1 through Gate 3 and then passing the same one-way low-head turbine that was built in the power house. Then, the water flows into Basin 2 before flowing back into the sea via Gate 2. See the pathway with dash line to illustrate it is flow direction. This will make the turbine is rotating again in the same direction which this process also will generate the electricity. It also can be said that the low-head turbine has a head at the 'X' side whereas it is tail at the 'Y' side. From this suggested form, the weaknesses from the simple-emptying scheme can be improved which is the interruption generation can be avoided. This can be done by assuring that the Gate1 and Gate 4 only will be opened when the water sea level achieved the maximum height level during the floods. During the ebbs, the water sea level must be at the lowest height. Then, Gate 2 and Gate 3 can be opened.

The scenario of the water sea level, water in basin level and it is relation with the power generation time can be depicted from Figure 2.

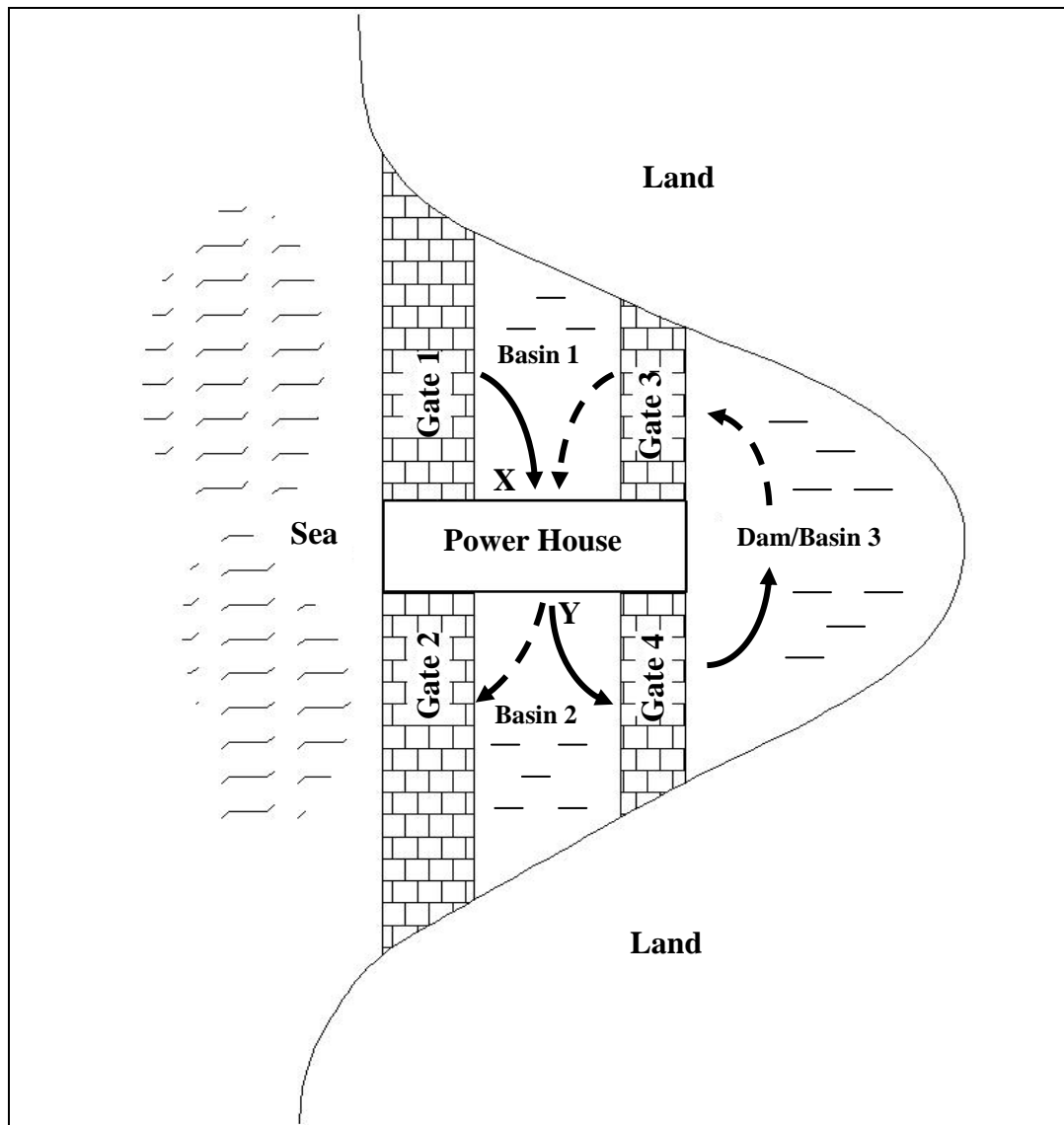


Figure 1: Suggested with passages in the dam in the form of the letter 'H'

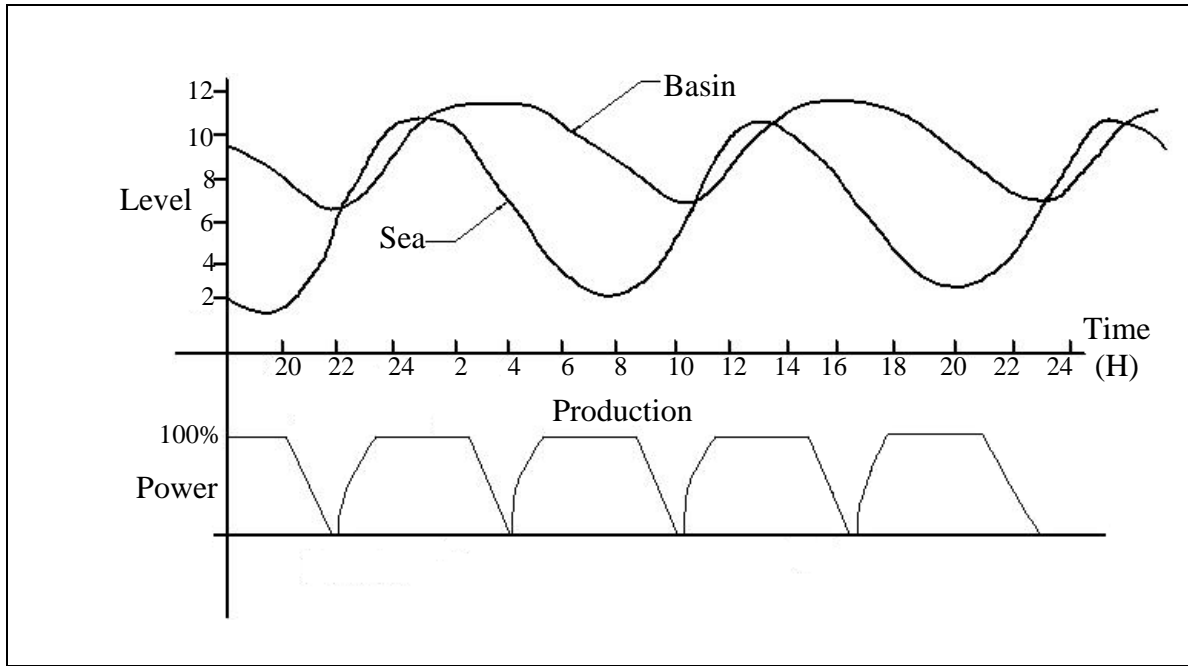


Figure 2: Output of double-emptying scheme [5]

When the sea water level reaches to the maximum height (around 1.00 am), the water level in the basin is still increasing towards its maximum height. When time goes on, sea water level will start decreasing (at 2.00 a.m), and the water level in the basin will be increasing until it reaches the maximum height level (at 5.00 a.m), then, the water level in the basin will start to be released. It generates the power during the water inflow and outflow into the basin. During every interchange tide into the basin which is from the lower to the high and from the high to the lower, the turbine was started to rotate slowly and will result in lower power generation. This can be seen by observing at the higher and at the lower side of Figure 2.

3.1 Production of Power

Power generation using double-emptying scheme can be calculated by using Equation (1):

$$P = \frac{1}{2} A \rho g h^2 \quad (1)$$

Where,

P = Power generated in Watt

ρ = The water density (The density of seawater is 1025 kg/m^3)

A = horizontal area of the basin (m^2)

h = tidal range (m)

The mass of the sea water can be estimated using equation (2) as

$$\begin{aligned} \text{Mass of the sea water} &= \text{Volume of the sea water} \times \text{density of sea water} \\ &= (\text{area} \times \text{tidal range}) \times \text{mass density} \end{aligned} \quad (2)$$

Whilst, the power in the pool during high tide can be calculated using equation (3) as below

$$\text{Power of the water in the pool at high tide} = \frac{1}{2} \times \text{area} \times \text{density} \times \text{gravitational acceleration} \times \text{tidal range squared} \quad (3)$$

Actually, in a day, there are 2 high tides and 2 low tides, therefore the total energy potential per day can be computed as equation (4)

$$\text{Total energy potential per day} = \text{energy single tide} \times 4 \quad (4)$$

Therefore, the mean power generation potential can be estimated using equation (5) as

$$\text{The mean power generation potential} = \text{energy generation potential} / \text{time each 6 hour} \quad (5)$$

4.0 Simulation Results

This section explains the results that have been simulated based on the best location in Malaysia by using Matlab/Simulink. The estimation of the generated potential power by using one turbine was executed based on the data that has been taken at Port Klang, Selangor during year 2010. This is the latest data that available from the JUPEM (Jabatan Ukur dan Pemetaan Malaysia). As depicted from Figure 3, the energy output monthly for year 2010 is shown. The energy output has a shape of sinusoidal wave. From the figure, it can be seen that the maximum power can be generated in March (approximately 9.8926 MW), then followed with January, February, April and September. The minimum power is generated in June with approximately 6.151 MW. The trend shows that during four early months of the year, the power can be generated at the mean of 8MW. Then power decreased constantly around 6M along three months in May until July. Starting August, power is starting increasing again until December, with mean power around 7MW. This is due to the monsoon wind factor.

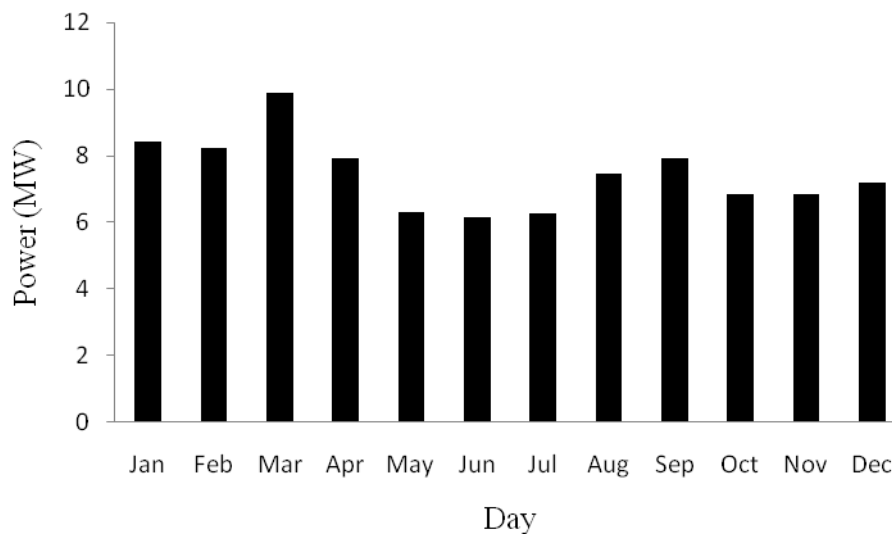
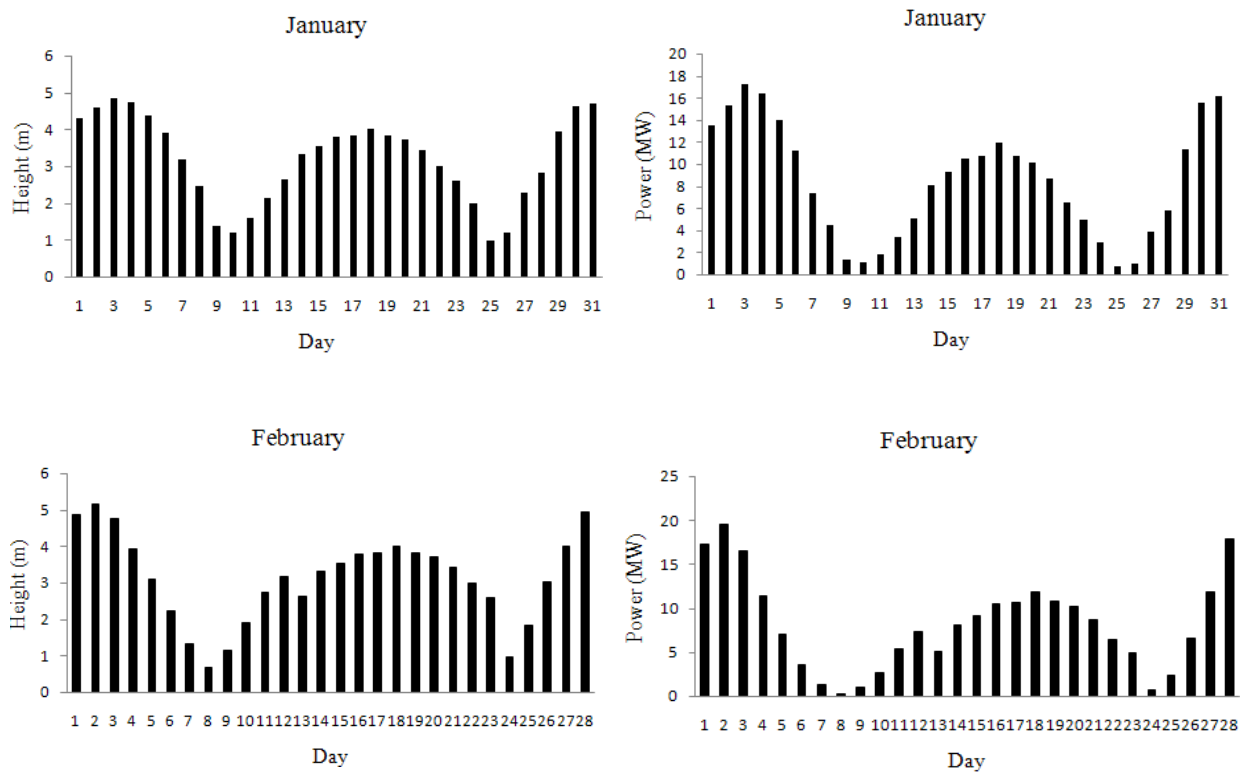
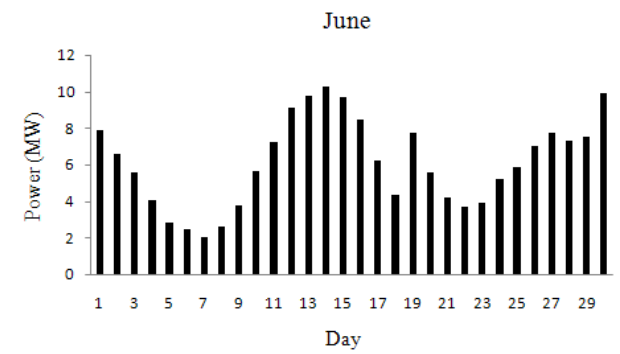
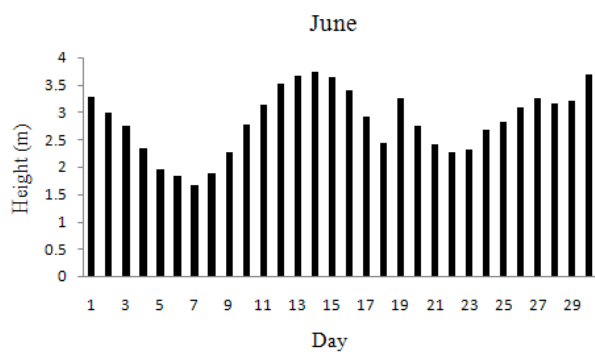
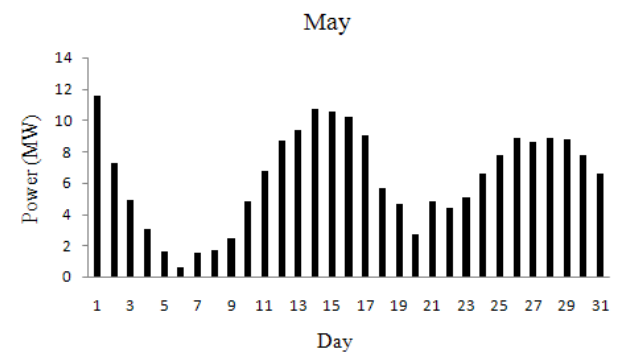
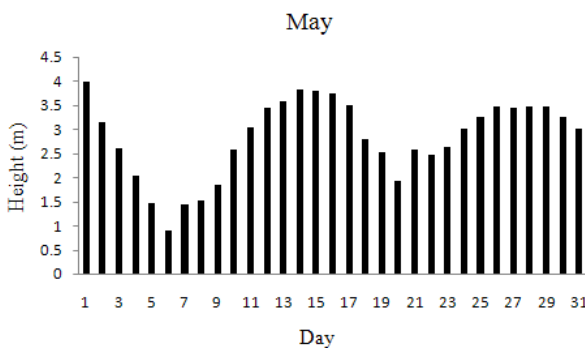
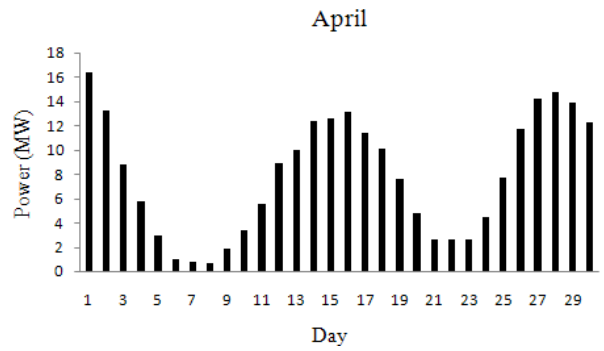
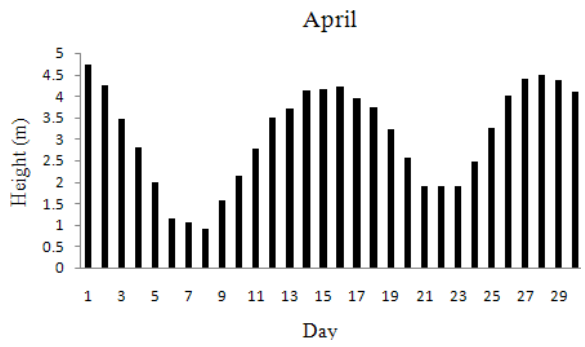
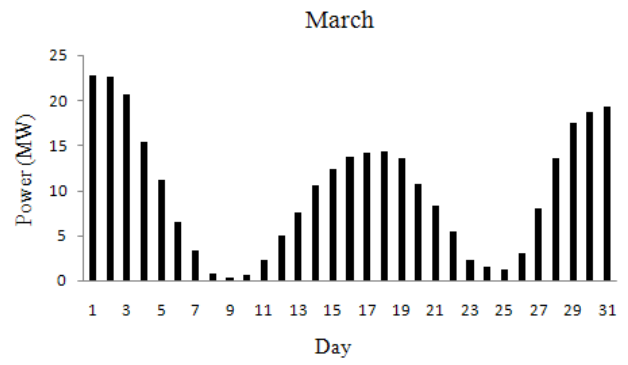
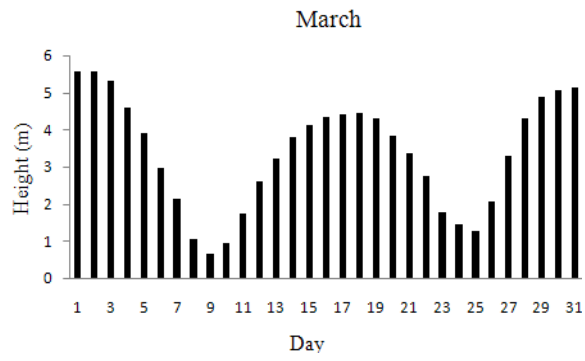


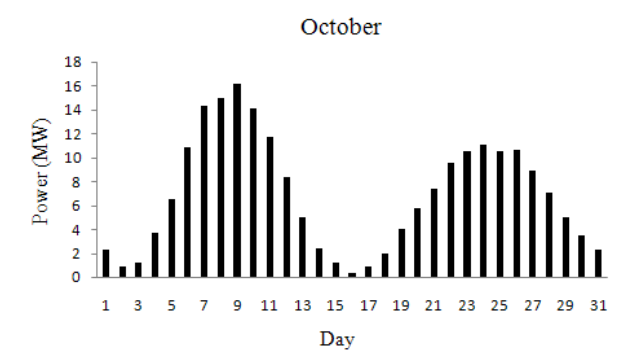
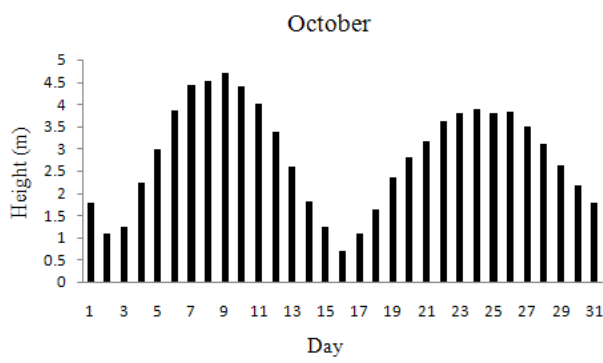
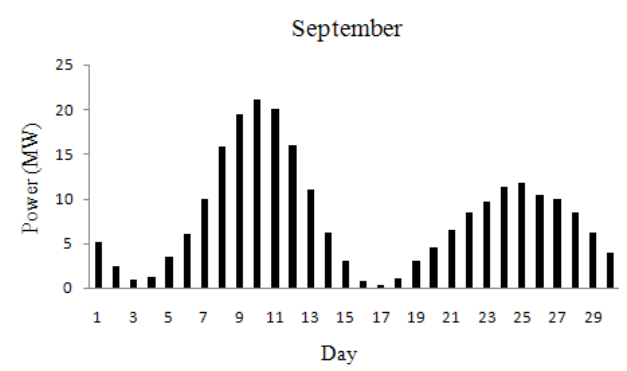
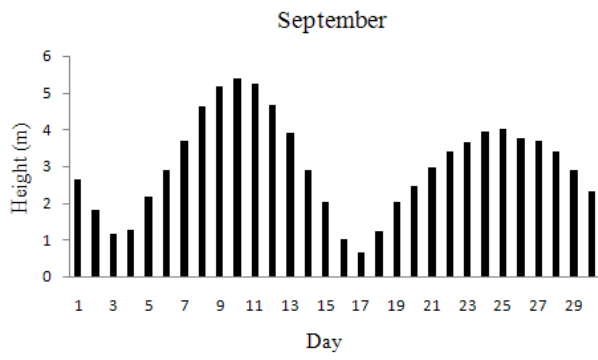
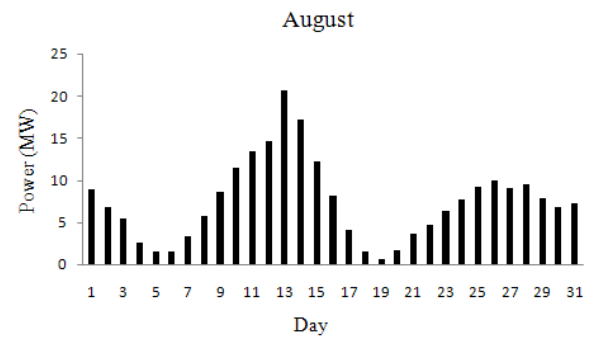
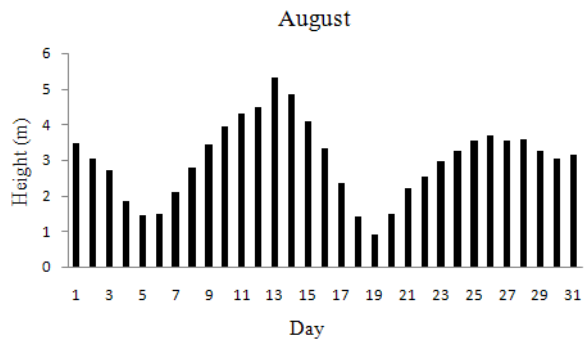
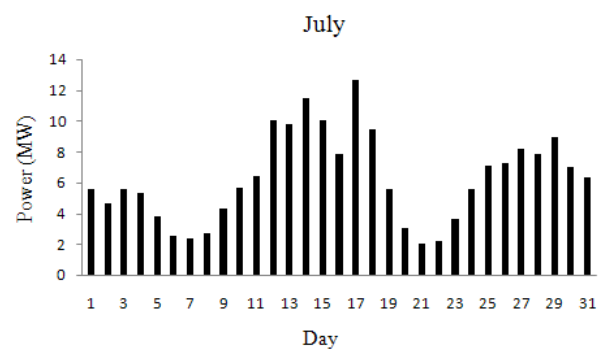
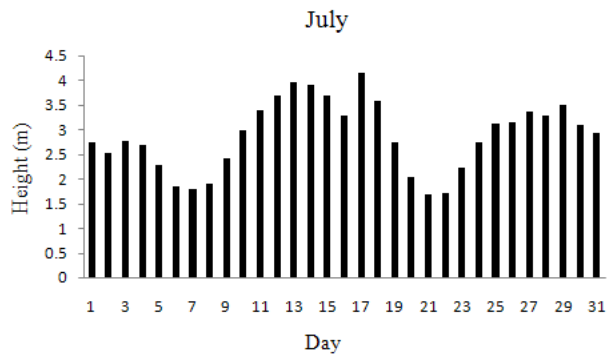
Figure 3: Power generated monthly

Figure 4 exhibits the daily and monthly power potential being generated at Port Klang in January until December. It can be seen that the power generated during these twelve months is identical. However, in terms of daily production, the daily outputs show an unstable generation pattern due to the daily difference tidal range. This is because generated power is proportionally to the water height difference where the difference water height is not similar or constant every day. However, from the pattern shown, it can be seen that from January to June, power can be produced greatly three times a month; during at the early, middle and end of the month. This is due to the difference water height experiencing a significant water height difference during this time. This is in contrast with the pattern shown for July until December where the power can be generated at maximum two times, at $\frac{1}{4}$ and $\frac{3}{4}$ of the month.

In annually, the maximum power can be generated in 2010 is in March with potential power up to 22.6MW on the 1st and 2nd March, with water difference of 5.57m. During this month, the mean power may reach about 9.8926 MW with mean water height of 3.38m. For March case, the lowest power is produced on 9th March which the power produced is about 0.3 MW with the difference height of 0.64m. Also from the observation from Figure 4, the minimum power being generated during this year is in June. The mean generated power and tidal range in this month is about 6.151 MW and 2.84m, respectively. This is the lowest mean generated power along this year. The summary of the mean tidal range and the mean potential power that can be generated during year 2010 is shown in Table 1.







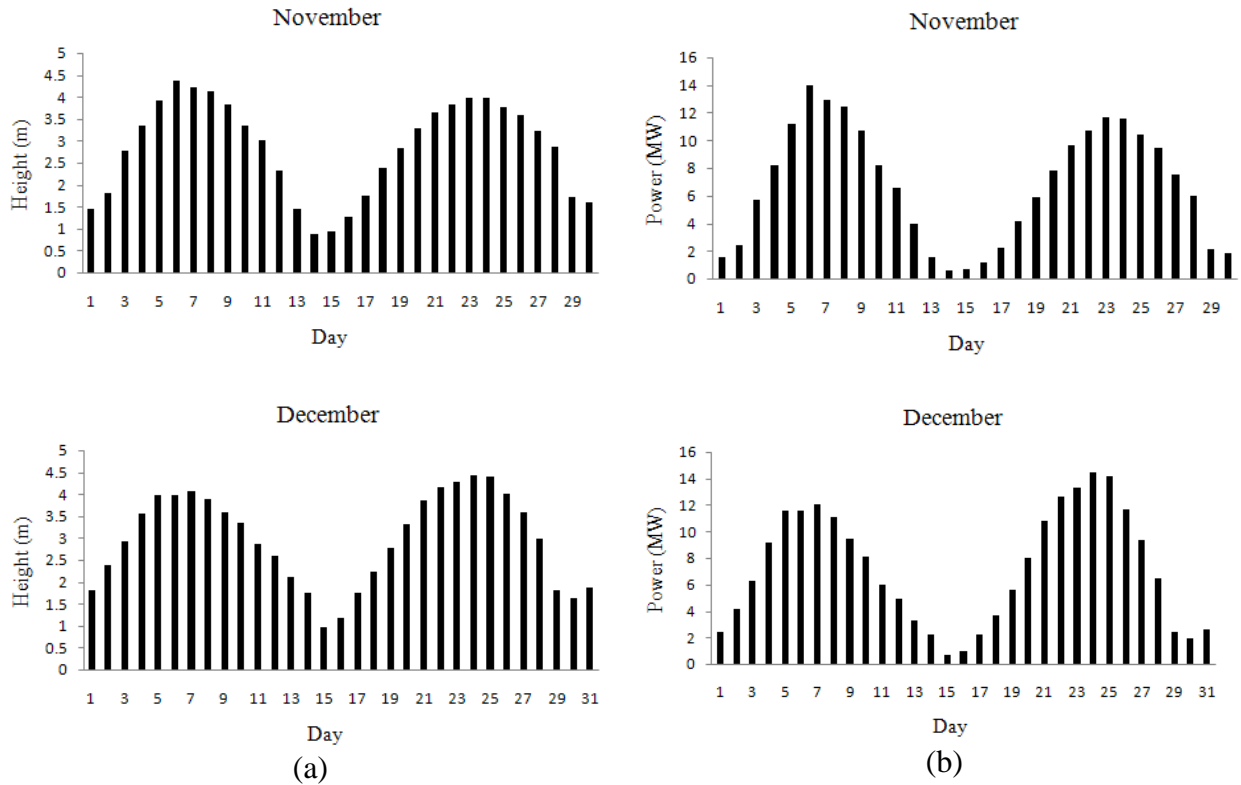


Figure 4: (a) The water height difference, (b) The generated power, from January to December 2010

Table 1: The mean height and mean power monthly for 2010

| Month | Mean tidal range(m) | Mean power generated |
|-----------|---------------------|----------------------|
| January | 3.19 | 8.4177 MW |
| February | 3.13 | 8.2129MW |
| March | 3.37 | 9.8926 MW |
| April | 3.09 | 7.9287 MW |
| May | 2.83 | 6.3126 MW |
| June | 2.84 | 6.151MW |
| July | 2.88 | 6.2690 MW |
| August | 3.02 | 7.4642 MW |
| September | 2.93 | 7.9213 MW |
| October | 2.84 | 6.8639 MW |
| November | 2.85 | 6.8337MW |
| December | 2.97 | 7.1913MW |

5.0 Conclusion

The double-emptying system for the new scheme of tidal generation method was proposed. The potential power that can be generated using the proposed system during year 2010 at Port Klang is presented. Based on the amount of power productions during this year, the tidal power be able to supply some small areas at the Port Klang. It is relevant if this power can be used directly during its production and the shortage remaining amount should be back-up from the grid. From the geometry location, Port Klang seems as a strategic place to implement the double-emptying system since Port Klang is far away from the large waves and sea erosion. This is therefore can reduce the cost of maintenance, particularly the dam's structure and

generator. This tidal generation is reliable and practical to be commercialized in a small-scale, and it's safe from any negative impacts on environment. In addition, it can overcome the 'stopped-generation' problem in the barrage system. However, more detailed studies are needed to investigate the viability and practicality of this approach, particularly in terms of increasing the maximum power generated. It is forecasted that if a pumping system is considered in the developed system, the amount of the generated power can be increased. This is, however, the topic in ongoing research.

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