The Energy Output from the Kuching Barrage in East Malaysia

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Abstract—Electricity generation from the sea has many advantages in comparison with other renewable energy resources. Power can be generated from new or existing barrages. Based on previous location research, a suitable system to produce tidal range energy from a potential site was developed in this paper. The main objective of this research is to calculate the energy output of the Kuching Barrage of Sarawak State of Malaysia. The daily flushing process of Kuching Barrage is conducted during the low tide period and therefore to put up the ebb generation process is appropriate. The calculated period of power generation is determined to about 6 hours. The annual energy output is calculated based on a theoretical method, with the average daily potential energy calculated to be 5.8MW and approximately 10.23GWh/year could be harnessed. This research can be beneficial for energy generation with the use of a double basin scheme for the construction of new barrages in East Malaysia.

Keywords-generation; Kuching Barrage; energy output; potential energy; Malaysia

I. INTRODUCTION

The oceans possess a huge potential of generating electrical power [1]. The generation of electricity from oceans offers many advantages when compared with other renewable energy sources [2]. Oceans are now globally established as mainstream renewable sources of energy [3]. It is calculated that the theoretical ocean energy resources are over 30,000TWh/year and the net potential power is larger than wind and solar power combined [4]. Malaysia is a big producer of solar Photovoltaic (PV) panels and is ranked as the world's third-largest producer of solar PV energy [5]. Although Malaysia is located at the equatorial zone and surrounded by sea, the ocean potential power has not been given full attention by the Malaysian government [6]. The country's total coastline is 4,675km with West and East Malaysia having 2,068km and 2,607 km of coastline respectively [7]. The vast area of Malaysia's coastline is a huge advantage making tidal range energy a reliable alternative energy source [8]. Tidal range energy is convertible and can be used at a big scale for sustainable electrical power generation [9]. Tidal range power is produced due to the consistent rise and fall of seawater [10, 11]. Tidal range power can be generated where the tidal range flow is available which means that it cannot be generated inland [12]. In Malaysia, the overall renewable energy creation is 32% of the yearly target. Malaysia has to restore its responsibility regarding accomplishing the target of electricity generation from renewable sources.

Worldwide, there are a few barrage plants in operation. The Sihwa dam in Korea and La Rance in France have mounting energy capability of 254MW and 240MW respectively [14, 15]. The described project supports the government's endeavors of electricity production from renewable energy resources and promotes tidal range energy. Unlike other known renewable energy resources, tidal range is an expectable phenomenon. Energy productions from a tidal range power can be assessed appropriately [13].

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II. Literature Review and Methodology

A. Methods of Calculating Potential Energy and Annual Energy Output

The theoretical calculation method is based upon derived equations. For tidal barrage, basin size and mean tidal range have important influence on power generation. Equation (1) shows the correlation of potential energy in mean tidal range enclosed in a basin [16]:

$$E_P = 0.5 \rho g A_b \Delta h_b^2 \quad (1)$$

where E_p is the potential energy over a tide cycle (GJ), ρ is the density of sea water (1025kg/m^3), g is the acceleration of gravity (9.81m/s^2), A_b is the horizontal area of the basin (km^2), and Δh_b is the monthly or annually mean tidal range in the basin (m). The factor 0.5 is its average value. The total basin area bounded by Kuching Barrage is 1430km^2. However, this may not be valid when used for power generation therefore Google maps was used to calculate the area.

For coastal areas where tidal range power generation is economically attractive, the tidal regime generally consists of two flood and two ebb tides, with a semi-diurnal period of 12.42h at the low tide when the potential energy is zero. Therefore, the total potential energy per day from the barrage approximates to 24/12.42 E_p, and the corresponding mean potential power can be written as:

$$\overline{P} = 24/12.42 E_p / 86400 \quad (2)$$

where $\overline{P}$ is the power in (GW), and E_p is the potential energy over a tide cycle (GJ) and time (s) [14].

Authors in [14] worked on the calculation of annual energy output from a tidal barrage. At the Severn Barrage, UK, researchers used a method for approximating the annual tidal energy output from a barrage. The total annual energy output from a barrage was calculated from the theoretical energy of tidal dynamics in the map of the Bristol Channel and Severn estuary with the site of the Severn Barrage [14]. It was suggested that the energy available from a barrage depends on the area of the water surface seized by the barrage and the mean tidal range h. Thus, the potential annual tidal energy output from a barrage can be considered as [17]:

$$E_{yr} = 0.987 A_b \Delta h_b^2 \eta \quad (3)$$

where E_{yr} is the potential annual tidal power output (GWh/year), A_b is the horizontal area of the basin (km^2), Δh_b is the tidal range in the basin (m), and η is the efficiency. The constant value 0.987 as mentioned in (3) is the converted value of tidal cycles per year [17]. The per cycle value is 1397 and the world mean period for tides is 12 hours and 24 minutes, hence, there are 706 tidal cycles per year, and therefore the converted value is 0.987kWh [17].

To sum up, the power output over a tide cycle can be calculated by using (1). Total potential energy per day can be calculated by (2). The relationship of (1) and (3) is that (1) can be used to calculate the daily potential energy and (3) can be used to calculate the annually power output. Authors in [18] researched the potential energy generation on total 34 sites at Sabah and Sarawak, Malaysia and identified 18 sites as suitable for the construction of a barrage to generate energy. Moreover, these suitable sites were supposed as preliminary, as the final sites should be supposed after conducting a feasibility study. Among the 18 sites, 2 sites were selected as having the maximum potential. The maximum potential power calculated sites were at the Tanjung Manis and at the Pending. The maximum energy potential was calculated to come from Tanjung Manis and was measured between 50.7kW and 39.2kW, while the second highest power was calculated for Pending, between 33.1kW and 25.1kW.

In continuity of the above research, the calculation of potential energy and annual energy of a tidal range energy extraction barrage at the Kuching is calculated in the current research.

B. Calculation of Potential Energy and Annual Energy Output:

To calculate the potential energy over a tide cycle, (1) will be used to calculate the mean potential energy in a day. The calculation is completed by using (2) whereas (3) is used to calculate the annual energy output. The annual calculation power output was calculated with the theoretical method. The annual output power is calculated with the lower power conversion efficiency.

III. Results and Discussion

A. Calculated Basin Area of Kuching Barrage

The basin area of Pending site at Kuching Barrage is calculated to get the potential energy and annual power output. The total basin area bounded by Kuching Barrage is 1430km^2, however, this may not be valid when used for power generation. Hence, it is assumed that the total bounded area may not be the effective area contributing to power generation. The effective basin area has been assumed as 2.94km^2.

B. Daily Power Output Calculation

Based on (1) and with a mean tidal range of 4.2m, Kuching Barrage potential energy value is 260GJ over a tide cycle. The daily potential energy is about 520GJ with nil potential energy during the low tide. In demand to get daily power output, the potential energy is distributed with the tidal period. The tidal period of semidiurnal tidal form is 12.42h or 44712s. The daily potential energy is 24/12.42. Equation (2) is used to calculate the daily potential energy. Thus, Kuching Barrage expected mean daily potential energy is 0.0058GW or 5.8MW. However, the energy output may not be continuous during the 12h cycle (ebb tides occur twice a day) operation due to the changing sea level. The Kuching Barrage energy plant is calculated to produce energy output power for 6h. However, generation duration could accept dependency on tide pattern. Due to this reason the mean tidal range reduces as the downstream water increases. As the mean tidal range decreases in height the power generation also reduces.

Figure 1 shows a simple cycle of power generation during the operation of Kuching Barrage gate. Phases I, II, and III are respectively for filling, holding and generating. There is a 12h operation during the ebb tide, a 6h generation and a 6h filing of the basin. The schedule of opening the Kuching Barrage gates to flush out the water to the sea depends on the tide level. The average schedule of opening the gates is 4-5h and sometimes 6-7h, depending on the tide level. Flush out water to downstream is possible when there is a low tide. The main aim of Kuching Barrage is to flush out river water before upstream got flooded during rainy season. The flush out of the upstream water to the downstream is possible twice a day as of low and high tides.

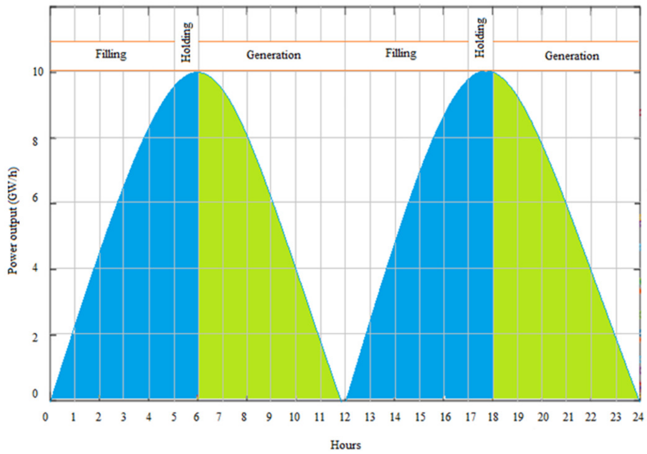

Fig. 1. A simple cycle of power generation.

C. Annual Power Output Calculation

Annual energy output is calculated by (3). At a minimum, 10.23GWh/year (η_P = 20%) of power can be harnessed with the lowest efficiency. Table I summarizes the power output value of Kuching Barrage tidal energy plant system. In Table I, the actual and theoretical annual energy output from different tidal power plants [14] are listed. Table I documents the technical conditions of the tidal power plants, with the actual output and theoretical calculation range of the annual energy output from each plant. Table I also depicts the installed capacity, basin area, and mean tidal range of 5 main tidal power plants. Tidal range energy schemes were measured by low standards of power conversion efficiency, frequently reaching from 20% to 40%, (with an average of 33%). However, minimum power conversation efficiency (20%) is used to calculate the power output for this project. The mean tidal range is the monthly or yearly average. In Table I, the theoretical standards are tabulated and are related to a present tidal energy plant to confirm the calculation methods.

Summarizing, Kuching Barrage is an additional proposed tidal power plant. The calculated basin area of Kuching Barrage is 2.94km^2 with calculated mean tidal range is 4.2m. The annual power output is calculated based on the lowest power conversion efficiency of 20%. The expected power output for Kuching Barrage tidal energy plant Malaysia is calculated as 10.23GWh/year.

Table II shows the power output of the Kuching Barrage tidal energy plant. The mean daily potential energy is calculated by (2). The potential annual power output is calculated by (3) at the lower efficiency of 20%.

TABLE I. COMPARISON OF THEORETICAL AND ACTUAL POWER OUTPUT OF TIDAL POWER PLANTS

Country	Site	Installed capacity (MW)	A_b (km^2)	Δh_b (m)	E_{yr} range at η = 20% (GWh/yr)	Actual or expected output (GWh/yr)
France	La Lance	240	22.5	8.5	320.90	533
Canada	Annapoils	20	6.0	6.4	48.51	50
China	Jiangxia	3.9	1.37	5.1	8.88	6-7
Korea	Shiwa	254	43	5.6	266.19	553
UK	Severn	8640	570	7.5	6329.14	15600
Malaysia	*Kuching Barrage	-	2.94	4.2	10.23	10.23

*Kuching Barrage at Pending site is our proposal for a tidal power plant scheme

TABLE II. CALCULATED POWER OUTPUT OF KUCHING BARRAGE TIDAL RANGE ENERGY PLANT SCHEME

Power estimation	Value
Mean daily potential energy, $\overline{P}$	2.8MW
Potential annual power, E_{yr}	5TWh/year (η= 20%)

IV. CONCLUSION

Tthe potential energy and annual power output of the Pending site at the Kuching Barrage basin area were calculated in this paper. The basin area of Kuching Barrage has been considered as 2.94km^2. The daily flushing process of Kuching Barrage is for the period of low tides and therefore is appropriate to put up the ebb generation process. The calculated period of power generation is determined to about 6h. Thus, the expected mean daily potential energy of Kuching Barrage is 5.8MW. The minimum annual energy output is calculated to be 10.23GWh/year.

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