

Suitable Turbine Selection based on the Parameters of a Potential Site at Sarawak, Malaysia

Kamran Ahmed Samo

Department of Electrical Engineering
Quaid-e-Awam University of Engineering, Science and
Technology, Sindh, Pakistan
kamransamo2@gmail.com

Imran Ahmed Samo

Department of Energy & Environment Engineering
Quaid-e-Awam University of Engineering, Science and
Technology, Nawabshah, Pakistan
imran.samo@yahoo.com

Waqas Mughal

Department of Mechanical Engineering
Quaid-e-Awam University of Engineering, Science and
Technology, Nawabshah, Pakistan
enr.pirbux@outlook.com

Andrew Ragai Henry Rigit

Mechanical Engineering Department
Universiti Malaysia Sarawak,
Sarawak, Malaysia
arigit@unimas.my

Arslan Ahmed Sohoo

Department of Electronic Engineering
Quaid-e-Awam University of Engineering, Science and Technology
Larkana Sindh, Pakistan
arslanahmed@quest.edu.pk

Abstract—The tidal range is a renewable energy source. In Malaysia, most of the produced renewable energy is generated from the exploitation of the tidal range. The main purpose of this research is to determine a suitable system to produce tidal range energy from a potential site. A turbine selection chart is used. The mean tidal range of Kuching Barrage is 4.2m and the maximum flow rate over a gate is 226.9m³/s. Therefore, for the extraction of electrical power, a bulb-type turbine with a rated power of 5.2MW is identified as suitable to be deployed at the site.

Keywords—tidal turbine; power; energy output; flow rate

I. INTRODUCTION

Ocean renewable energy sources are globally established as mainstream sources of energy [1]. It is calculated that the theoretical ocean energy resources are over 30,000TWh/year and the net potential power is larger than the sum of wind and solar power [2]. Malaysia is one of the biggest producers of solar photovoltaic (PV) panels and is ranked as world's third-largest producer of solar PV energy [3]. However, ocean energy resources like tidal range energy can be used at a big scale for sustainable electrical power generation [4]. Tidal range power is produced due to the consistent rise and fall of seawater [5, 6]. Tidal range power can be generated where tidal range flow is available [7]. Energy from tidal range can be used for electrical power generation. A potential site to generate renewable energy from tidal range at the East Coast of Malaysia can be determined [8]. Power could be generated

from the existing or a new barrage, in the isolated regions of East Malaysia. This research found that bulb type turbine can be selected as the applicant turbine for Kuching Barrage. The selected turbine is proposed for electricity production in the Sarawak state of Malaysia.

The aim of this research is to determine a suitable turbine for a suitable location at Sarawak. Kuching Barrage is identified as a potential site that could yield 10.23GWh energy per year. The hypothesis of the research is that turbine selection is based on calculated parameters of potential sites, including tidal range and flow rate.

II. LITERATURE REVIEW

A. Selection of the Tidal Range Turbine

Turbine selection is mostly dependent on the accessible tidal range and flow rate. The flow rate is used to conclude the turbine capacity. Tidal barrage turbines usually have a low tidal range turbine. The lowest water range required for the operation of the turbine is between 1 and 1.5m. However, the most of tidal range power plants use low tidal range [8]. Turbine efficiency and price are side factors. There are various turbine types of calculated tidal range, flow rate, and appropriate power [10]. There are four different types of turbines: Pelton, Francis, Kaplan, and bulb type turbines [9]. The calculated ranges are between 50kW and 1,000MW and the flow rate values vary from 1.0 to 1000m³/s.

Corresponding author: Kamran Ahmed Samo

B. Tidal Range Calculation

Tidal range is defined as the difference between the water level in low and high tides. In the present study, one way power generation is assumed. Therefore, the difference in water level has been taken as the difference of high and low tide:

$$h = h_t - l_t \quad (1)$$

where h is the tidal range (m), h_t is the high tide (m), and l_t is the low tide (m).

Q_s is defined as the discharge of water through a turbine. The water discharge through sluice gates Q_s can be designed based on its association with the consistent mean tidal range.

$$Q_s = C_d A \sqrt{2gh} \quad (2)$$

where Q_s is the discharge through the sluice gate (m^3/s), C_d is the discharge coefficient of the sluice gate (generally larger than 1), A is the flow area through the hydraulic building (m^2); g is the acceleration of gravity ($9.81m/s^2$), and h is the mean tidal range (m) [11]. Similarly, by using (2), the flow rate can be calculated for each gate of the barrage.

C. Turbine Rated Head and Power for a Single Turbine

Equation (3) is used to calculate the turbine rated head for mean tidal range lesser than 9m. The constant value 0.66 can be used for a single high basin plant with one direction and for conventional bulb type turbine [12]. By using (3), the rated head of a turbine can be achieved. In (3), *Mean Tidal Range* is the same with h (2):

$$H_r \approx 0.66 \times \text{Mean Tidal Range} \quad (3)$$

Equation (4) is used to calculate the rated power for a single turbine in MW [12]. The power output can be achieved by using (4). The number 8.22 is a turbine constant value taken from [13], whereas the number 1000 in the denominator is used for conversion from GW to MW:

$$P_r = \frac{8.22 Q_s H_r}{1000} \quad (4)$$

III. METHODOLOGY

A. Method of Turbine Selection

The selection of a suitable turbine will be conducted using the calculated parameters (tidal range and flow rate) of a site. The turbine presentation plan will be used to choose the appropriate turbine agreeing to the parameters of the chosen site. The turbine should not conflict with the current size of the barrage gates. The turbine should be capable to work effectively at the lower tidal range of the selected site. In order to install a turbine at the selected site, the turbine parameters will be determined according to the parameters of the selected site.

B. Tidal Range and Flow Rate Calculation

For the calculation of tidal range, the tidal data for the year 2015 of the Kuching Barrage site will be utilized. The tidal pattern can be semi diurnal, diurnal and mixed, e.g. Sarawak is semi diurnal. Considering that Kuching Barrage is located in Pending, it is assumed that the tidal pattern observed at Pending

is similar to the tidal pattern at Kuching Barrage. Statistical analysis will be performed with Sigma software for the calculation of the tidal range. Histograms of a tidal range of each month will be plotted with the annual tidal range information of the site. On the information of histogram plots the annual mean tidal range and the monthly mean tidal range will be determined. In Sigma, all data must be stacked first before any graph is to be plotted.

Tidal range and flow rate calculations are essential for turbine selection. The energy extraction from a potential site requires the data of tidal range and flow rate. Low and high tides of each day have been collected and the tidal range was determined by (1). Gate flow rate was calculated from (2). For the duration of the flushing process, the barrage gates are opened by 1m from the upstream (basin side). The opening space of the barrage gates will be considered to discover the real discharge at the barrage gate. Table I presents the data of Pending site for the January of 2015. The second column shows the high tide water level and the third column shows the low tide water level. The tidal range in the third column is calculated from (1). The data show that the mean of the tidal range is 4.1m.

TABLE I. HIGH AND LOW TIDE WATER LEVEL AND TIDAL RANGE OF PENDING SITE, JANUARY, 2015

| Day | High tide water level (m) | Low tide water level calculation (m) | Tidal range (m) |
|-----|---------------------------|--------------------------------------|-----------------|
| 1 | 5.2 | 1.6 | 3.6 |
| 2 | 5.3 | 1.4 | 3.9 |
| 3 | 5.5 | 1.2 | 4.3 |
| 4 | 5.7 | 1.0 | 4.7 |
| 5 | 5.8 | 0.9 | 4.9 |
| 6 | 5.8 | 0.9 | 4.9 |
| 7 | 5.8 | 0.9 | 4.9 |
| 8 | 5.7 | 1.0 | 4.7 |
| 9 | 5.6 | 1.2 | 4.4 |
| 10 | 5.5 | 1.4 | 4.1 |
| 11 | 5.3 | 1.7 | 3.6 |
| 12 | 5.2 | 2.0 | 3.2 |
| 13 | 5.0 | 2.3 | 2.7 |
| 14 | 4.9 | 2.3 | 2.6 |
| 15 | 4.9 | 2.2 | 2.7 |
| 16 | 4.6 | 2.0 | 2.6 |
| 17 | 4.9 | 1.7 | 3.2 |
| 18 | 5.3 | 1.4 | 3.9 |
| 19 | 5.7 | 1.0 | 4.7 |
| 20 | 6.0 | 0.7 | 5.3 |
| 21 | 6.2 | 0.4 | 5.8 |
| 22 | 6.3 | 0.3 | 6.0 |
| 23 | 6.3 | 0.3 | 6.0 |
| 24 | 6.2 | 0.6 | 5.6 |
| 25 | 6.0 | 1.0 | 5.0 |
| 26 | 5.7 | 1.5 | 4.2 |
| 27 | 5.4 | 1.6 | 3.8 |
| 28 | 5.1 | 1.7 | 3.4 |
| 29 | 4.8 | 1.8 | 3.0 |
| 30 | 4.9 | 1.7 | 3.2 |
| 31 | 5.1 | 1.9 | 3.5 |

C. Turbine Rated Head and Power of One Turbine

To calculate the turbine rated head, (3) will be used. For calculating the rated power of a turbine, (4) will be used.

IV. RESULTS AND DISCUSSIONS

A. Parameters at Kuching Barrage

To select a suitable turbine for Kuching Barrage, it is important to determine the parameters of Kuching Barrage. The tide tables are used to calculate the tidal range of the Pending site.

B. Tidal Range of Kuching Barrage

To calculate the tidal range and to analyze the tidal pattern of Pending, the information from the tide tables of 2015 is used. The mean tidal range is 4.2m and, as can be seen in Figure 1, the maximum tidal range is 6.2m. It can be seen that low tidal ranges (from 1.7m to 2.0m) have low occurring frequency while higher ranges (2.4m-6.2m) are more frequent.

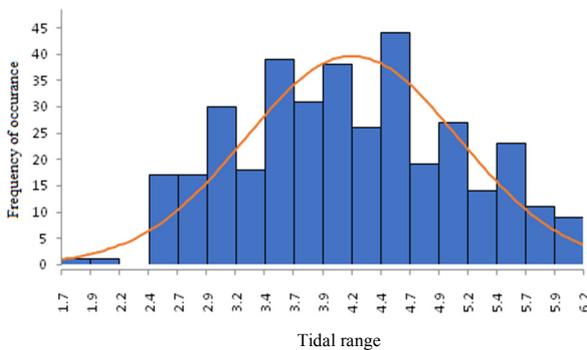


Fig. 1. Graph of calculated tidal range in 2015 at Pending.

Table II depicts the maximum, minimum, and the mean values for the tidal range of each month of the Pending region. The lowermost tidal range, observed in December, was 1.7m and the maximum value, observed in October, was 6.2m. The highest peak mean tidal range recorded was 4.2m. The results do not relate to the monsoon, however they may seem like as coming from a hydroelectric dam. As the power generated from the barrage is one way (power generation is only generated during the low tide) and as per actual measurements of the tides it is visible that low tides are almost similar, which may be the reason of small variations in calculations.

TABLE II. PENDING SITE TIDAL RANGE IN 2015

| Month | Maximum | Minimum | Mean |
|-----------|---------|---------|------|
| January | 6.0 | 2.6 | 4.1 |
| February | 6.0 | 2.8 | 4.2 |
| March | 5.8 | 2.9 | 4.1 |
| April | 6.0 | 2.8 | 4.2 |
| May | 5.8 | 2.7 | 4.2 |
| Jun | 5.4 | 2.6 | 4.1 |
| July | 5.6 | 2.7 | 4.1 |
| August | 5.8 | 2.7 | 4.2 |
| September | 6.0 | 2.6 | 4.1 |
| October | 6.2 | 2.6 | 4.3 |
| November | 6.0 | 2.0 | 4.2 |
| December | 5.6 | 1.7 | 4.1 |

C. Water Flow Rate of Kuching Barrage

The water flow through the barrage gate is calculated by

(2). During the flushing process, the barrage gates are mechanically unlocked by 1m from the upstream [14]. The Kuching Barrage opening area of each gate is 25m² while the gate width is 25m. One more parameter in defining water flowing rate is the “discharge coefficient” which is supposed to be equal to 1 [11]. On 4.2m tidal range and supposing discharge coefficients equal to 1, the total flow of four gates of Kuching Barrage is calculated to be 907.7m³/s (gate 5 is reserved for emergencies). The water flow calculated for each gate is 226.9m³/s.

D. Turbine Selection based on Kuching Barrage Parameters

A turbine should be capable to work powerfully at low tidal range values. The turbine should not disturb the barrage gates’ size and ship lock. The turbine selection is based on tidal range and flow rate. For the selection of a suitable turbine, a presentation chart is used to choose the appropriate one. As shown in Figure 1, the mean tidal range is 4.2m and the mean flow rate is 226.9m³/s. For these conditions, the most appropriate turbine is the bulb-type turbine. Therefore, it is recommended to be installed at the Kuching Barrage.

E. Parameters of the Selected Turbine

1) Rated Head H_r

Equation (3) is used to calculate the turbine rated head for mean tidal range lower than 9m and a single basin tidal power plant.

2) Power of a Single Turbine

Equation (4) is used to calculate the rated power of a turbine for $Q_s = 226.9m^3/s$ and $H_r = 2.772m$. The rated power is measured in MW. Table III depicts the calculated (bulb type) turbine parameters and the Kuching Barrage parameters. The rated head is calculated by (3), the gate flow rate is designed by (2), and the throat area of the turbine is calculated with the help of the turbine diameter and the area of a circle. The rated power output for a single turbine is calculated by (4). The turbine diameter is logically measured based on the space between the LSD of Kuching Barrage gate and the lowest tide level. The mean tidal range is the average of all mean tidal range values. Gate flow rate is calculated by (2). The basin area is calculated with the help of Google Maps.

TABLE III. PENDING SITE TIDAL RANGE OF EACH MONTH OF 2015

| Parameter | Symbol | Value |
|----------------------------|--------|------------------------|
| Rated head | H_r | 2.772m |
| Throat area of the turbine | F | 4.3m ² |
| Rated power output | P_r | 5.2MW |
| Turbine diameter | D_t | 2.35m |
| Mean tidal range | H | 4.2m |
| Gate flow rate | Q_s | 226.9m ³ /s |
| Basin area | A_b | 2.94km ² |

F. Mechanical Components of the Selected Turbine and its Functions

The main mechanical components of the bulb-type turbine are a Kaplan runner, guide vanes, a propeller shaft, bearings, and the generator. The draft tube is the runner opening passageway of the turbine, fronting to the sea region in the

Kuching Barrage tidal energy plant system. The key purpose of the draft tube is to decrease the velocity out of the turbine throat space. The Kuching barrage draft tube is 11.32m long. Guide vanes are important to modify the water flow in the runner agreeing to the design angles of the runner blades. The bulb-type turbine has two radial bearings to the horizontal shaft and provides thrust in the process [15, 16].

G. Power Output Calculations

The study exhibited that Kuching Barrage has the potential for power generation by the installation of tidal range turbines suitable for a tidal energy plant. The potential energy and the annual power output are calculated.

H. Calculated Basin Area of Kuching Barrage

The basin area of Kuching Barrage was measured as 2.94km². The total basin area bounded by the Kuching Barrage is 1430km². 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 power generation. The effective basin area has been assumed as 2.94km².

V. CONCLUSION

Pending's mean tidal range is about 4.2m and the discharged flow rate of a single gate is 226.9m³/s. The bulb-type turbine is proposed as the most applicable turbine for Kuching Barrage. The calculated diameter of the bulb-type turbine is 2.35m. The bulb-type turbine is planned to be installed at four gates of Kuching Barrage. The rated power is about 5.2MW/turbine.

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