Assignment Tidal Energy

OFFSHORE RENEWABLES TECHNOLOGIES /
MARINE RENEWABLE TECHNOLOGIES

OE44170/CIEM4305

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1 Part 1a: Environmental Data and Tidal Resource

1.1 Constituents data for tidal stream resource

The data used for group 2 is as follows:

- $M_2 = 2.2185$ m/s
- $S_2 = 0.4335$ m/s
- $K_2 = 0.4437$ m/s

1.2 Velocity profile

The velocity profile is created on the basis of the harmonic function as follows:

$$V(t) = \sum_i A_i cos(2\pi f_i t + \phi_i) \tag{1}$$

$$f_i = 1/T_i \tag{2}$$

- $A_1 = M_2 = 2.2185$ m/s
- $A_2 = S_2 = 0.4335$ m/s
- $A_3 = K_2 = 0.4437$ m/s
- $T_{M2} = 12.42$ hours
- $T_{S2} = 12$ hours
- $T_{K2} = 11.97$ hours
- $\phi_i = 0$ (Assumption)

The resulting velocity profile along with the Neap and Spring tide cycles are as shown in figure 1.

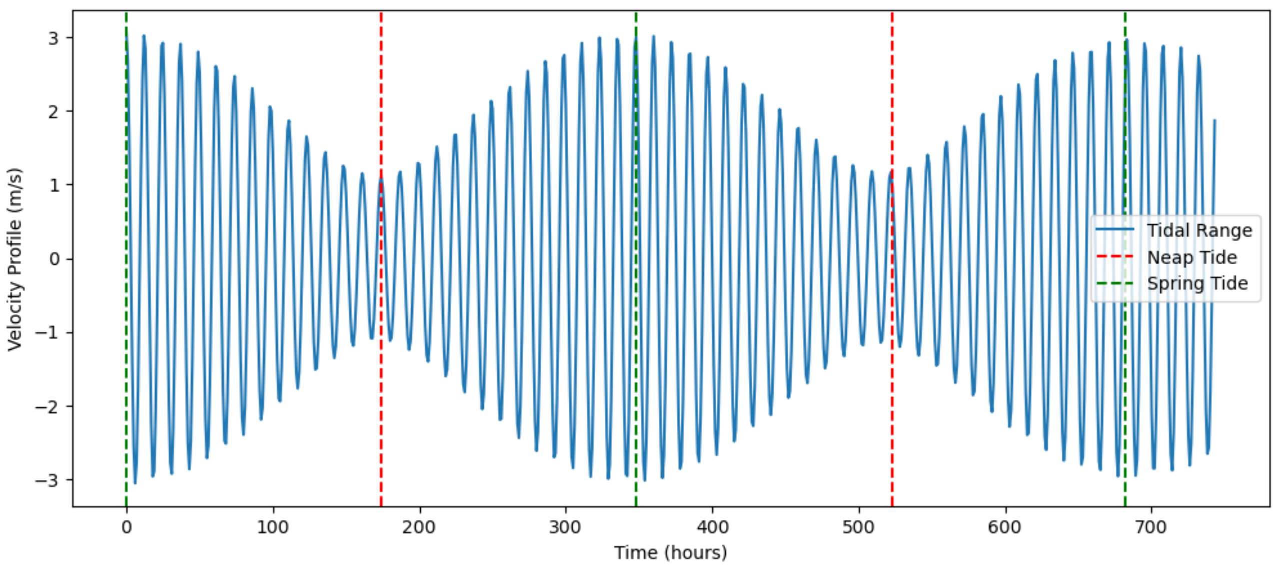

Figure 1: Velocity profile over 31 days

In the plot above, the distance between the two green dashed lines is indicative of a duration of a spring cycle, while the distance between the red dashed lines represents a neap cycle.

2 Part 1b: Tidal Stream Energy Production

In order to calculate the kinetic energy flux through the capture area A, it is used the equation below:

$$P(t) = \frac{1}{2}\,\rho\,A\,\overline{U_l}^{\,3} \tag{3}$$

where

- U_l denotes the local tidal current speed for spring or neap at the turbine location. Although because our turbine is bidirectional both spring and neap velocities were taken into account. To achieve this, the absolute velocity was taken into account. Additionally, the velocities were shorted because the turbine does not produce below cut-in $v_{\mathrm{ci}} = 1.0m/s$ or above cut-out $v_{\mathrm{out}} = 3.0m/s$, so only the interval between was included.

Given:

- Rated power: $P_{\text{rated}} = 1.0\,\mathrm{MW}$
- Total efficiency (water → electricity): $\eta = 0.45$
- Capture area: $A = 165\,\mathrm{m}^2$
- Water density: $\rho_{\text{water}} = 1025\,\mathrm{kg\,m^{-3}}$

The estimated annual mean power is

$$P_{\text{annual}}(t) \;=\; \eta\,\frac{1}{2}\,\rho\,A\,\overline{U_l}^{\,3}, P_{\text{annual}}(t) \;=\; 0.45 * P(t) = 0.18MW \tag{4}$$

The maximum power produced is

$$P_{\text{max}} = 1.02MV \tag{5}$$

Annual energy yield

$$\mathrm{AEY} \;=\; \int_0^{T_{\mathrm{yr}}} P(t)\,dt \;=\; \overline{P}\,T_{\mathrm{yr}} \tag{6}$$

$$\mathrm{AEY} \;=\; T\sum_{i=1}^{N} P_i\,f_i, \qquad \sum_{i=1}^{N} f_i = 1 \tag{7}$$

Because our dataset is sampled every hour, each time interval has equal weight, i.e. $f_i = 1$. Therefore, the expression reduces to

$$\mathrm{AEY} \;=\; \sum_{i=1}^{N} P_i\,\Delta t, \qquad \Delta t = 1\,\mathrm{h}. \tag{8}$$

So, AEY = 1540.66 MWh

Capacity factor

$$\mathrm{CF} = \frac{\overline{P}}{P_{\mathrm{rated}}} = \frac{\mathrm{AEY}}{P_{\mathrm{rated}}\,T_{\mathrm{yr}}}. \tag{9}$$

$$\mathrm{CF} = \frac{\sum_t P_i}{P_{\mathrm{rated}} \times 10^6 \times 8760} = 0.18. \tag{10}$$

3 Part 2: Operation of a Tidal Rage Powerplant

The one-way ebb generation tidal power plant is described as follows:

- The minimum head for power generation, $H_{se} = 3\ \mathrm{m}$
- The minimum head for filling the basin, $H_{se} = 1\ \mathrm{m}$
- Basin Area $A_{basin} = 10\ \mathrm{km}^2$
- Total capacity of 10 bulb turbines, $P_{rated} = 200\ \mathrm{MW}$
- Turbine diameter, $D = 7\ \mathrm{m}$

- Turbine efficiency $\eta = 90\%$
- Total outward discharge during energy generation, $Q_t = 5000 \text{ m}^3/\text{s}$
- Total area of the sluice gates, $A_{sluice} = 500 \text{ m}^2$

The water elevation inside the basin is described by the backward scheme as shown below and is implemented using a loop in python.

$$Z_{i+1} = Z_i + \frac{Q_i}{A_{basin}}\Delta t \tag{11}$$

where $\Delta t = 0.1h$ denotes the time step and Q_i the total flow rates at time t_i.
The head difference H is described as follows.

$$H_i = \eta_{sea} - Z_i \tag{12}$$

where η_{sea} is the tidal level.
The total water flow rate through sluices and turbines during filling is described as follows.

$$Q_s(t) = C_d A_s \sqrt{2gH(t)} \tag{13}$$

where C_d is the coefficient of discharge (assumed to be 1.0), and A_s is the total area opening of sluices and turbines, and H(t) is the head difference between the tide elevation and the basin.
The power output from a single turbine during generation is given by the following expression.

$$P(t) = \rho g H(t) Q_t(t) \eta \tag{14}$$

Relevant plots

Figure 2 illustrates the water level and the head difference over 14 days of data. It illustrates two tidal cycles. We see that the head difference between the basin and the sea drops when the water level in the basin drops and it increases when the water level in the basin increases.

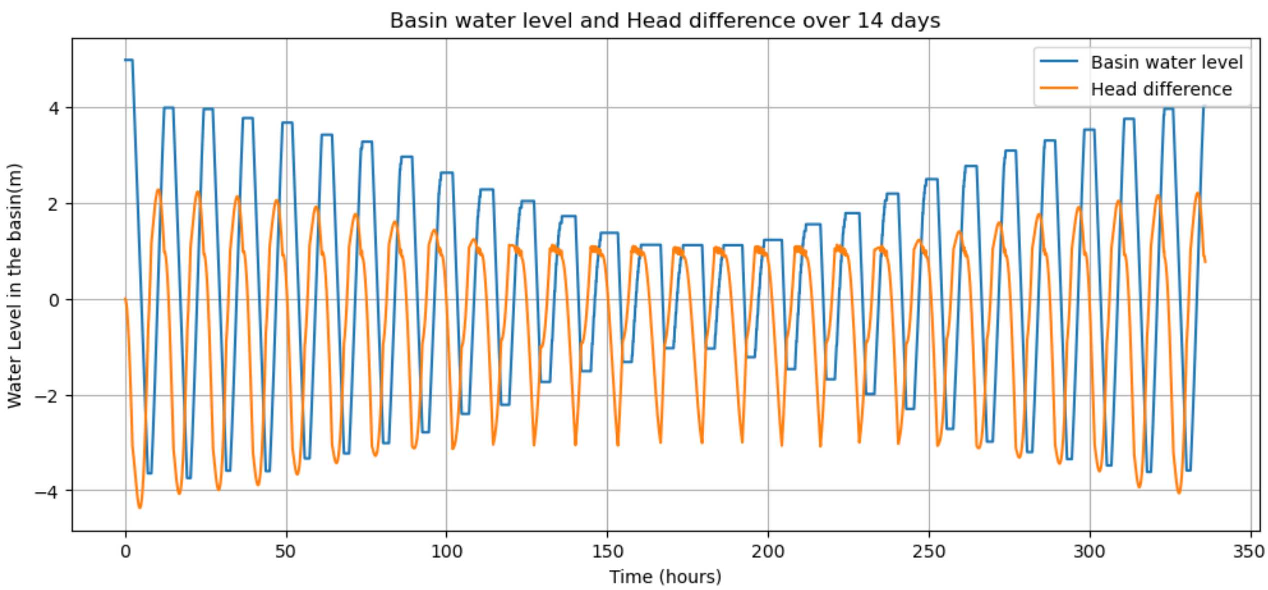

Figure 2: Basin water level and head difference over 14 days

Figure 3 zooms in on a 24 hour period to illustrate the relation between the head difference, the basin level, the sea level and the power generated. We see that the head difference decreases as the distance between the sea level and the basin water level decreases and it increases if we have the opposite.

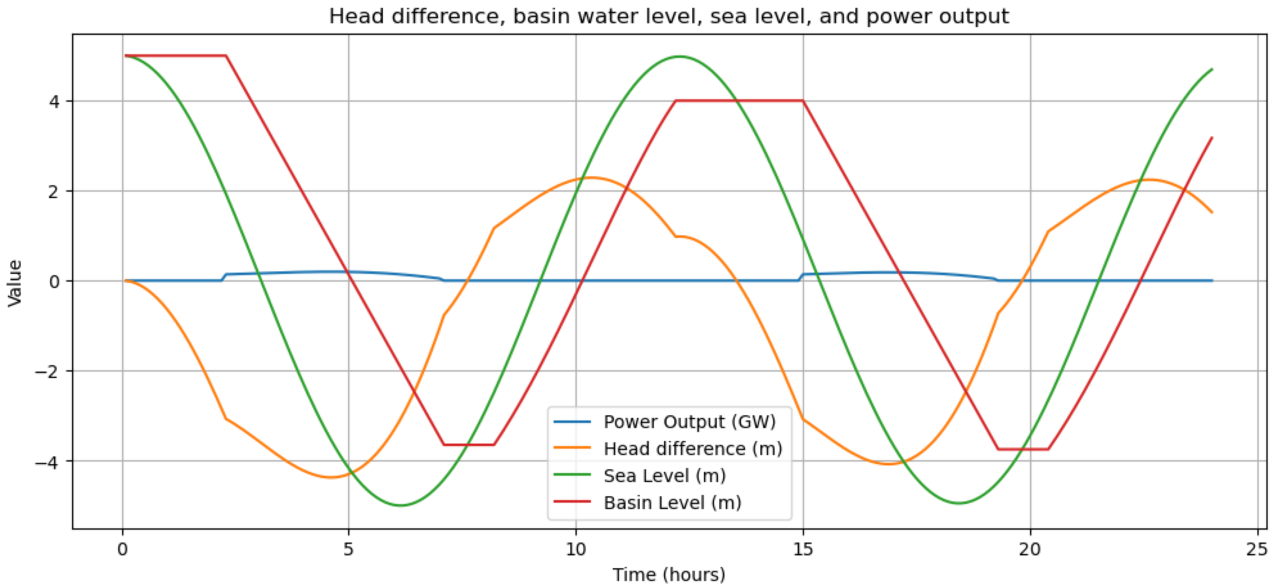

Figure 3: Head difference, sea level and basin level over 24 hours

Figure 4 illustrates the basin level and the sea level over 50 hours. We can observe that the basin level follows the seal level with a small time shift. This is the time it takes to empty or fill in.

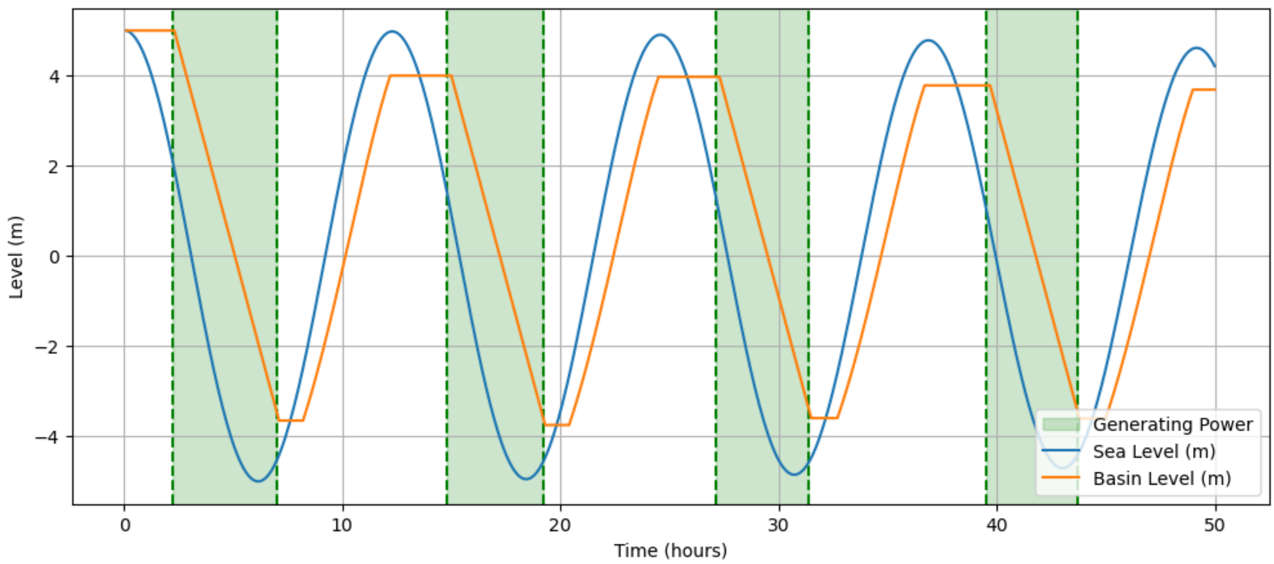

Figure 4: Basin level and tidal level over 50 hours

Finally, Figure 5 illustrates the flow rate and the total power produced over 50 hours. Since the power plant generates power during ebb, it will only generate power when the discharge is negative (flow out of the basin). This is what is seen in Figure 5. The power output is only nonzero when the flow rate is negative. Furthermore, the flow rate changes from negative to zero to positive. When the flow rate is zero, the head difference is not sufficient to generate a flow. When the flow rate is positive, the basin is filling up and the head difference is large enough. Finally, when the flow rate is negative, the basin is emptying and power is generated.

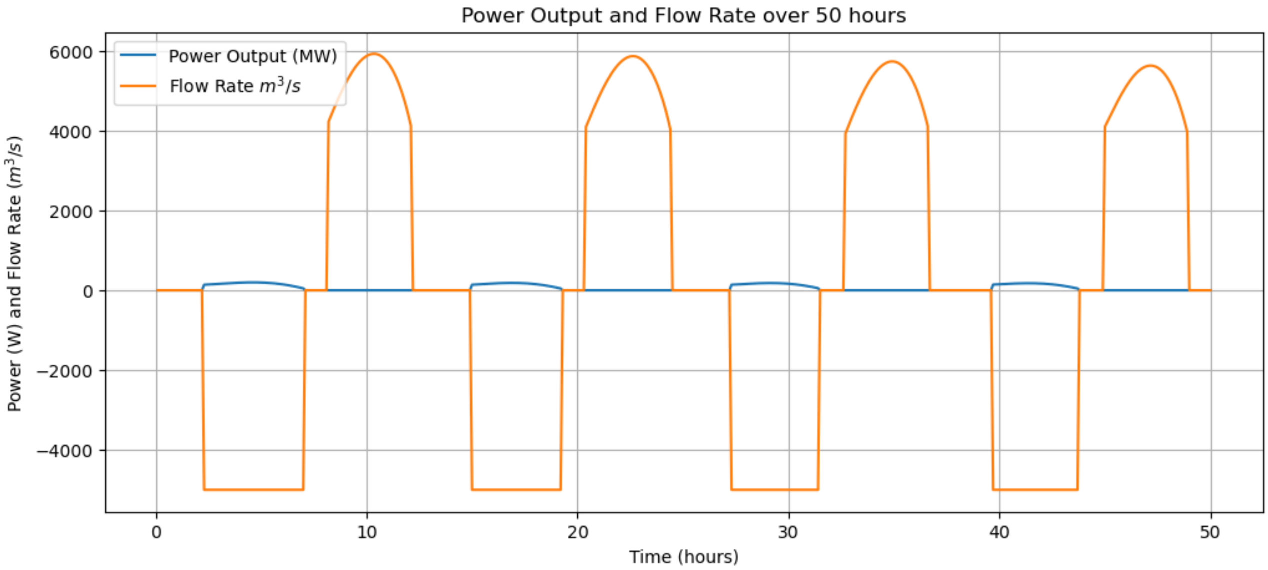

Figure 5: Total power produced and flow rate over 50 hours

3.1 Relevant Energy Information

The annual mean power and the maximum power produced are as follows:

$$P_{mean} = 30.25 \ MW \tag{15}$$
$$P_{max} = 197.72 \ MW \tag{16}$$

The annual energy yield and the capacity factor are computed as follows:

$$AEY = \frac{\sum P \cdot 24.377}{1e6 \cdot 10} = 247728 \ MW \tag{17}$$
$$C.F = \frac{AEY}{200 \cdot 8760} = 0.14 \tag{18}$$

For the annual energy yield, we had to divide by 10 again to go from 0.1 hours to hours. Furthermore, the rated power of the turbine is 200 MW. This is used in the calculation of the capacity factor.