A Comprehensive Study of Sea Wave Tidal Power Plant (PLTPS)

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Abstract: The use of fossil fuel sources to power plants is a major problem in many countries in the world today. Among power plants that use water as an energy source, tidal energy is one alternative of renewable energy sources. This paper discusses all matters relating to tidal power plants (PLTPs) of the type, generation process, advantages and disadvantages as well as the subject of this study discussed three case studies of generators of two types of conversion, i.e., tidal range and tidal stream to see the characteristics of each plant. From the result of the case study, it can be seen that the prospect of the implementation of marine energy development especially the tidal energy is good enough to be seen from the potential of Indonesia sea that has the range and speed of current that fulfill the provisions, especially in some straits in eastern Indonesia.

1 INTRODUCTION

Energy use indirectly contributes to the high concentrations of CO2 in the atmosphere that have increased significantly over the last century. From some sectors of energy users, the electricity and heat generation sectors are the most widely used energy sources so as to be directly proportional to CO2 emissions into the atmosphere as shown in Figure 1 (IEA, 2015).

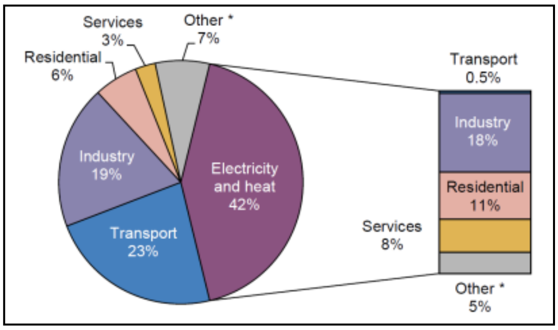

Figure 1: CO_2 emissions from various sectors in 2013

The use of fossil fuel for power plant has been an inevitable problem. Because of the negative effects caused by the release of CO2 into the atmosphere and the depleting supply of non-renewable sources of energy while the use of electric energy is increasing, then the use of renewable energy sources began to promote.

Tidal energy is one alternative source of renewable energy. The working principle is the same as hydroelectricity, where water is used to rotate turbines and generate electrical energy. Energy is derived from the utilization of sea level variations contained in the tidal mass transfer of water.

2 MATERIAL AND METHODS

2.1 Tidal Energy Conversion System

Tidal Barrage is a tidal utilization technology using barrage or dam. Energy is produced from the difference in sea tidal height. Electricity is generated through a turbine placed at the dam.

The dam extracts tidal energy from the height difference between water in the Dam and at sea. When the tide, water will enter into the Dam until certain conditions the water will be retained and released back through the water turbine when the water receded. From the process of tidal movement of water that moves the turbine in the Dam then, the electrical energy can be obtained.

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There are two main types of tidal reservoirs: single-basin and double-basin systems. Single Basin consists of one basin and requires a dike that cuts down the estuary or bay. There are three operating patterns in this system such as tidal generation, tidal generation and two-way generation as in Figure 2. Double Basin system requires the construction of two barrages, core and additional. The main basin is basically the same as the receding mode in a single basin system. The difference is that in this case some of the energy produced is used to pump water into the second basin. For this reason, the second dam acts as a storage element, extending the time period in which the dam can generate electricity as illustrated in Figure 3.

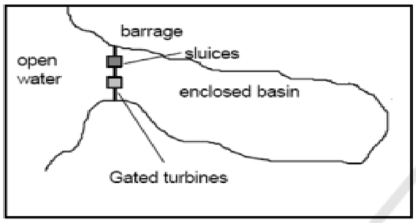


Figure 2: System Single Basin

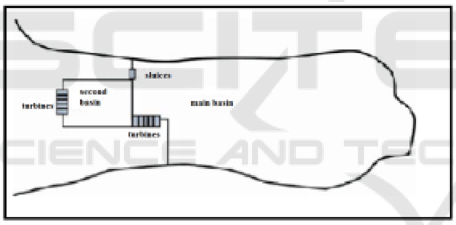


Figure 3: System Double Basin

Figure 4 describes the barrage type PLTPs component.

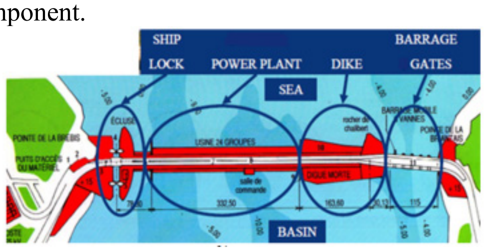


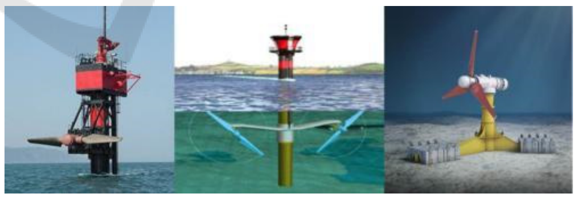
Figure 4: The layout of PLTPs type barrage component

Some components and its function as follows:
1. Gate: The gate controls the flow of water between the sea and the basin.
2. Substation: Ground generator to raise the voltage and interconnect to the network.
3. Basin: Water reservoir area at high tide and return water to the sea at low tide (low tide).
4. Inactive dike: Separation barrier.
5. Powerhouse: Generally, power plants use bulb turbines as their initial drivers.
6. Lock: The structure built between the sea and the basin that allows the ship or boat to pass.

2.2 Tidal Stream

Tidal Stream or tides that is the movement of seawater due to the tidal cycle, creating kinetic movement. The potential of this current is usually located near the coast; especially there is inhibiting the topography, such as inter-island straits. Turbines used in this technology are often called Free Flow Tidal Turbine (FFTT), have the same form and working principle with a wind turbine. The large density of seawater makes the current drive strong so that the FFTT can generate large electrical energy.

Currently, there are two types of turbines, horizontal axis turbine, and a vertical axis turbine. In the horizontal axis turbine (HAT), the blades are designed in the opposite direction with the direction of ocean currents due to the current velocity and direction of the current causing the turbine blades to rotate as in Figure 5. Turbine blades are below the rotating water surface on the horizontal axis parallel to the direction of the water flow. The optimum operating point of this turbine is at a current velocity between 4 and 5.5 mph (Khaligh, 20018). At the current velocity, a 15-meter turbine is capable of producing energy comparable to a 60-meter wind turbine. The strategic location of power plant placement with this type of turbine is near the coast at a depth of 20-30 meters.



(a) (b) (c)

Figure 5: (a), (b) 2 blades; (b) 3 horizontal blades

Vertical axis turbine (VAT) is designed perpendicular to the direction of ocean currents as shown in Figure 6. VAT has greater efficiency but is unstable, and the resulting vibration is higher. Another advantage is that the size of the blade on a VAT type turbine can be increased without any restrictions as in the HAT turbine type. Figure 7 describes the PLTPs component of the stream type.

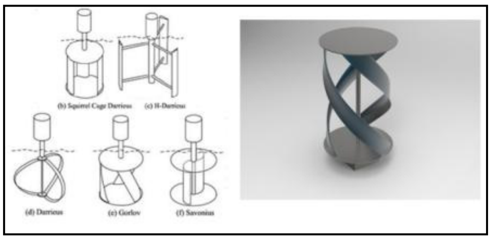


Figure 6: (a) vertical axis turbine; (b) gorlov turbine

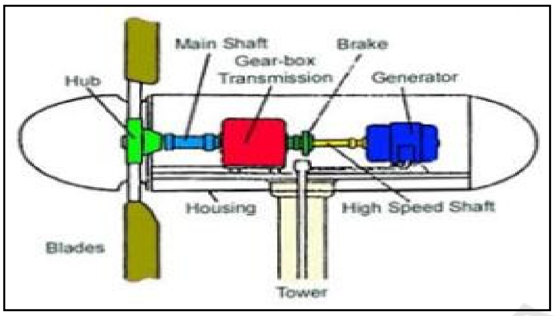


Figure 7: Component of PLTPs

2.3 Power on Turbine

To calculate the estimated power output of this turbine PLTPs used the following formula:

2.3.1 PLTPs System Dams (Barrage)

The capacity of a barrage type tidal turbine can be calculated by Equation 1 (Araquistain,-):

$$E = \frac{1}{2}\, A\, \rho\, g\, h^2 \qquad (1)$$

With: E = potential energy (J), A = the horizontal area of the dam (m^2), ρ = density of water (1025 kg/m^3) / (1021-1030 for seawater), g = the force of gravity of the earth (9.81 m/s^2) , h = the water level at the dam (m).

From Equation 1, we can calculate the power which can be generated using Equation 2:

$$P = \frac{\eta\, E}{t} \qquad (2)$$

With: P = Energy raised (W), η = turbine efficiency, t = time of operation (s)

2.4 PLTPs Flow Tide System (Stream)

Tidal current turbine capacity can be calculated by Equation 3 (Royal Academy of Engineering,-)

$$P = \frac{1}{2}\, \eta\, \rho\, A\, V^3 \qquad (3)$$

With: P = Energy raised (W), η= turbine effiency, ρ = density of water = 1025 kg/m^3, A = turbine coverage area (m^2), V= speed of water flow (m/s)

The literature review study was conducted by a systematic search on electronic databases: Web of Science, British Hydropower Associates (BHA), Indonesian Energy Outlook and several other publications. The search is then continued by scanning a list of references from relevant publications so that explanations of case studies can be more widely elaborated. The aspects reviewed include the following: location of construction, structure, and components, tidal potential, type of turbine, working cycle, generation capacity, and annual energy.

The case study discussed in this paper are 3 tidal power generation units. The three power generating units represent two types of tidal power and tidal current tidal ranges. The 3 units are La Rance, Sihwa, and Strangford Narrow as shown in Table 1.

Table 1: Case studies of PLTPS

	Generator Type	Generator Name	Location	Year of Development
Sea Tidal Power Plants	Tidal Range	La Rance	France	1966
		Sihwa	South Korea	2010
	Tidal Current	Strangford	Northern Ireland	2008

3 RESULTS

3.1 La Rance Tidal Power Plant, France

La Rance Tidal Power Plant is a tidal power plant built in the estuary of the river Rance in Brittany, France as illustrated in Figure 8. With a capacity of 240 MW and built in 1966 making it the oldest and second largest PLTPs in the world and generating an annual capacity of 540 GWh (BHA, 2009). With a tidal height of 8.2 m which is the largest tidal range in France the plant supplies electrical energy to a 225 kV national transmission network and illuminates ± 1300,000 homes annually.

The background of the construction of PLTPs at the mouth of this river includes the height of the largest tidal range including in France with an average of 8.2 m to a maximum of 13.5 m. The reservoir volume is 184,000,000m3, with more than 20km to the headwaters (22km2 basin area) and only 750 m wide by the mouth of the estuary.

a. Structure and Components

1. Powerhouse

Bulb turbines are placed on a 332.5m powerhouse dam.

2. Dam

Dyke or embankment on La Rance power plant has a length of 163.6m. with a barrage length of 145.1 m, 6 gates or a water gate with a height of 10 m, a width of 15 m and a maximum water flow of 9600 m^3/s with a basin area of 22 km^2 as illustrated in Figures 9 and 10.

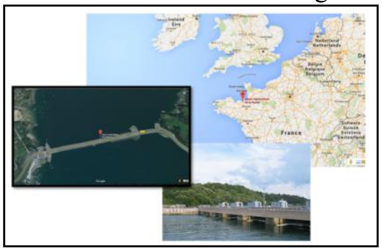


Figure 8: Location La Rance tidal power plant

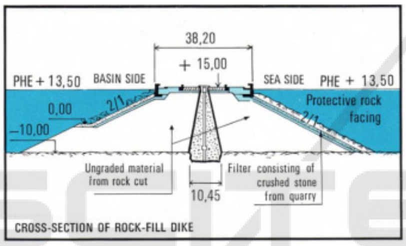


Figure 9: Construction dyke at La Rance tidal power plant

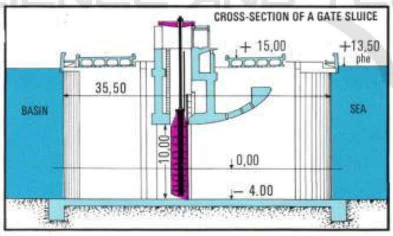


Figure 10: Construction Barrage at La Rance

b. Electric Supplies

In the La Rance tidal power plant, there are 24 x 10 MVA alternators operating in 2bar (28.44psi) pressurized air absolute pressing; AI 3.5kV. There are 6 units of operation with each 4 bulb turbine complete with supporting components for turbine and alternator adjustment. 3 transformer units (3.5 / 3.5 / 225kV) with 80MVA power, with OFAF cooling system and 225kV network connection using oil-filled cables under pressure.

c. Working Cycle

The work cycle on the La Rance tidal power plant is shown in Figures 11 and 12.

- 1-way generation (Tidal generation)
- 2-way generation (Tidal generation and generation on the rising tides)

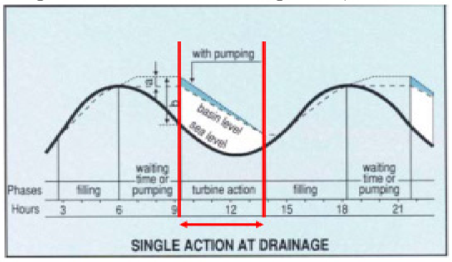


Figure 11: A 1-way work cycle at La Rance tidal power plant

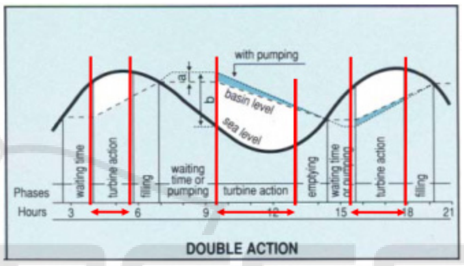


Figure 12: A 2-way work cycle at La Rance tidal

d. Turbine

The characteristics of turbine bulb used in La Rance PLTPs are 5.35 m diameter, weight: 470 t, Rated head 5.65 m, discharge at rated head 275 m^3/s, output 10 MW, rotation speed 93.75 rpm, max. over speed: 260 rpm, 4 blades (inclination: -5° to +35°), 24 guide vanes, minimum head: 3 m and maximum head: 11 m.

3.2 Sihwa Tidal Power Station, South Korea

Sihwa Lake Tidal power station is located 4 km from Siheung town in Gyeonggi Province South Korea As illustrated in Figure 14. With a capacity of 254 MW makes the Power plant is the largest PLTPs today. Power is generated by utilizing the rising tidal flow into a 30 km^2 basin using 10 turbine bulb units of 25.4 MW capacity. 8 water gates placed to release water from the barrage to the sea. This project cost $ 355.1m and was built between 2003 and 2010 generating an annual capacity of 552.7 GWh (Schneeberger, 2008).

a. Structure and Components

The construction of the Sihwa Lake tidal power plant is similar to the first case study, La Rance tidal power plant. For size, specifications can be seen in Figures 15 and 16.

b. Turbine

Technical Data for turbines used in Sihwa lake tidal power station is 10 bulb turbine diameter runner 7.5 m with output of 25.4 MW and output generator 26.8 MVA, Rated speed 64.3 rpm, Rated head 5.82 m, Rated discharge 482.1 m³/s, voltage rating 10.2 kV, current rating 1515 A, annual energy production is around 550 GWh.

c. Working Cycle

This power plant cycle uses a 1-way generation cycle that is a tidal generation, meaning that the flow of water used to turn turbines is a tidal stream. With data of basin area 56 Km2. This unit operates 2x in a day as illustrated in Figure 17.

Figure 14: Location Sihwa tidal power plant

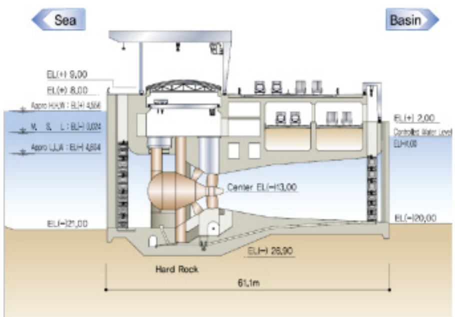


Figure 15: Construction of the powerhouse Sihwa tidal

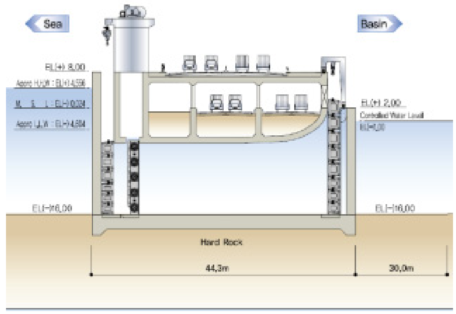


Figure 16: Construction dyke Sihwa tidal power plant

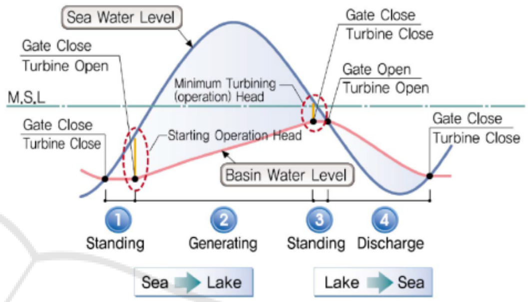


Figure 17: Sihwa tidal power plant work cycle

3.3 Strangford Narrows MCT, Northen Ireland

Seagen is the first large-scale commercial tidal power plant in the world. The first seagen was installed at Strangford Narrows between Strangford and Portaferry in Northern Ireland, England in April 2008 and connected to the grid in July 2008. The turbine generates 1.2 MW between 18 and 20 hours a day when tides rise and exit from Strangford Lough through a pronged cleft (Narrow) As shown in Figure 18. SeaGen S 1.2MW system is capable of generating up to 20MWh of energy per day in Strangford, whilst totaling 6,000MWh per year. This equals the average energy generated from the 2.4 MW wind turbine (MCT, 2013). The seagen turbine weighs 300t; each turbine drives the generator through a gearbox such as a water turbine or wind in general. This turbine has a feature where both blades can rotate up to 180 degrees allowing them to operate in both directions - on tidal and flood tides. The rotor can be lifted up through the water surface to anticipate when the current is too strong beyond the limit of the rotor's ability. Its feature design allows the S-turbine tidal stream turbine system to achieve 48% efficiency at various current velocities as illustrated in Figure 19.

Figure 18: Location of Seagen S tidal Stream Turbine

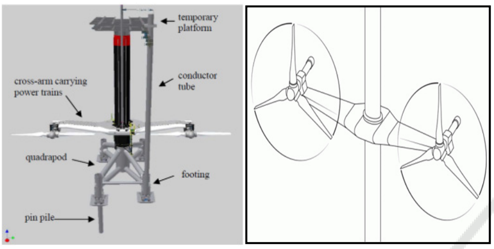


Figure 19: (a) Seagen S tidal Stream Turbine component; (b) visualization of the turbine sweep area

4 DISCUSSION

Comparing the two types of La Rance, France and Sihwa Korea generators, there are differences and similarities, that is, La Rance was built approximately 45 years earlier than Sihwa, obviously the development of technology makes it easier to build a similar power plant with a larger capacity where La rance capacity 240 MW with 24 turbines of 10 MW while Sihwa power plant uses 10 turbine units with a capacity of 25.4 MW. The diameter of the turbine sihwa is greater that is 7.5m while La Rance 5.35m. with half the cost of La Rance developer sihwa tidal power can build a plant with a better capacity of € 580m or equivalent to the US $ 656.44m, while the cost of building a tidal power plant of US $ 355.1m. it is because the existing embankment construction at Sihwa lake has been previously made for agricultural purposes. Another difference is seen from the work cycle in which the La Rance power plant works in two directions, the generation whereas the tidal power plant works in one direction where we know that in some places the tidal generation is less effective as the tidal generation because the water discharge is likely to be out of control. For tidal stream turbine type generation in accordance with the theory that the greater the area of turbine sweep with the same current velocity yields greater energy as attached in Table 2.

Table 2: Comparison between PLTPS

No.	Aspect of Review	PLTPS Unit		
		La Rance	Sihwa	Strangford
1	Location	France	South Korea	Northern Ireland
2.	Year	1966	2011	2008
3	Tidal height	8,2 m	6.3 m	-
4	Tidal current velocity	-	-	2,4 m/s
5	Conversion system	Barrage	barrage	stream
6	Type of turbine	Bulb	Bulb	Horizontal axis
7	D-runner turbine	5.35 m	7 m	16 m
8	Number of turbines	24 unit @10 MW	10 unit @ 25.4 MW	2 unit @ 600 kW
9	Working cycle	2 ways	1 way	2 ways
10	Capacity	240 MW	254 MW	1.2 MW
11	Annual energy	540 GWh	552.7 GWh	6 GWh
12	Developme nt costs	US$ 656. 44m	US$ 355.1 m	€ 3.6 m

5 CONCLUSION

From the results of the discussion we obtained the following conclusions:

1. PLTPs are subdivided according to their energy extraction method, i.e., potential energy that is vertical water movement associated with the ups and downs of tidal and kinetic energy which is the result of the horizontal motion of water which is also called as tidal current.
2. The prospect of the implementation of the development of marine energy utilization, especially tidal energy is good enough to be seen from the potential of Indonesia sea that has the range and speed of current that meet the requirements, especially in several straits in eastern Indonesia.
3. Location determination, selection of turbine type, and type of duty cycle are determined by the characteristics of the location itself either from its topology, tidal range, and its tidal current velocity.

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