CIVE 401

KAPLAN TURBINE

Term Project | by Kyle Kuhl, Kennard Lai, Dorian Lainel

Fall 2014

COLORADO STATE UNIVERSITY
EDUCATION · SERVICE · EXTENSION · RESEARCH · 1870

Instructor: Dr. Pierre Julien

Index

Overview

Figure 1: Viktor Kaplan. November 27, 1876 – August 23, 1934. (Wikipedia Public Domain)

The first recorded attempt to use a turbine with adjustable blades was in 1867, where O.W. Ludlow issued a patent for the idea. The Kaplan Bulb Turbine was originally developed by Victor Kaplan, an Austrian engineer, towards the beginning of the twentieth century. A Kaplan Turbine is a result by Kaplan by further improving the basic principles of the Francis Turbine by adding adjustable runner blades. The Kaplan turbine is different from its predecessor designs because the Kaplan turbine allows for a transition space which the flow direction transitions from radial to axial. Kaplan Turbines are often installed in large rivers. The Kaplan Bulb Turbine is a double-regulated turbine, and is most suitable for large flow and low head situations. The head experienced from the Kaplan Turbine can range anywhere from 1.5 meters (4.9 feet) to over 50 meters (164 feet). The Kaplan turbine operates most efficiently between heads of 1.5 meters and 15 meters. Over 15 meters, the efficiency of the turbine will start to decrease.

Kaplan Turbines can be horizontally or vertically oriented, depending on the input flow. The vertical orientated Kaplan Turbines allow for runner diameters up to 10 meters (33 feet). Efficiency of these Kaplan turbines can be increased by adjusting the inlet angle, the exit angles, the radius of the turbine, and the blade pitch angle. All of these factors are unique based on the flow rate of each specific location and flow scenario. Kaplan turbines are effective in nearly any region around the world, because they do not require much head. As long as there is relatively high hydraulic flow, a Kaplan turbine may be put into place.

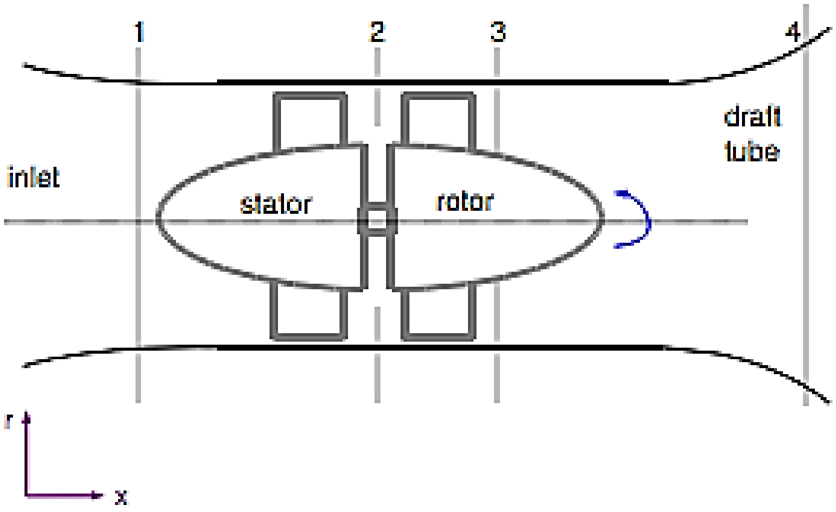
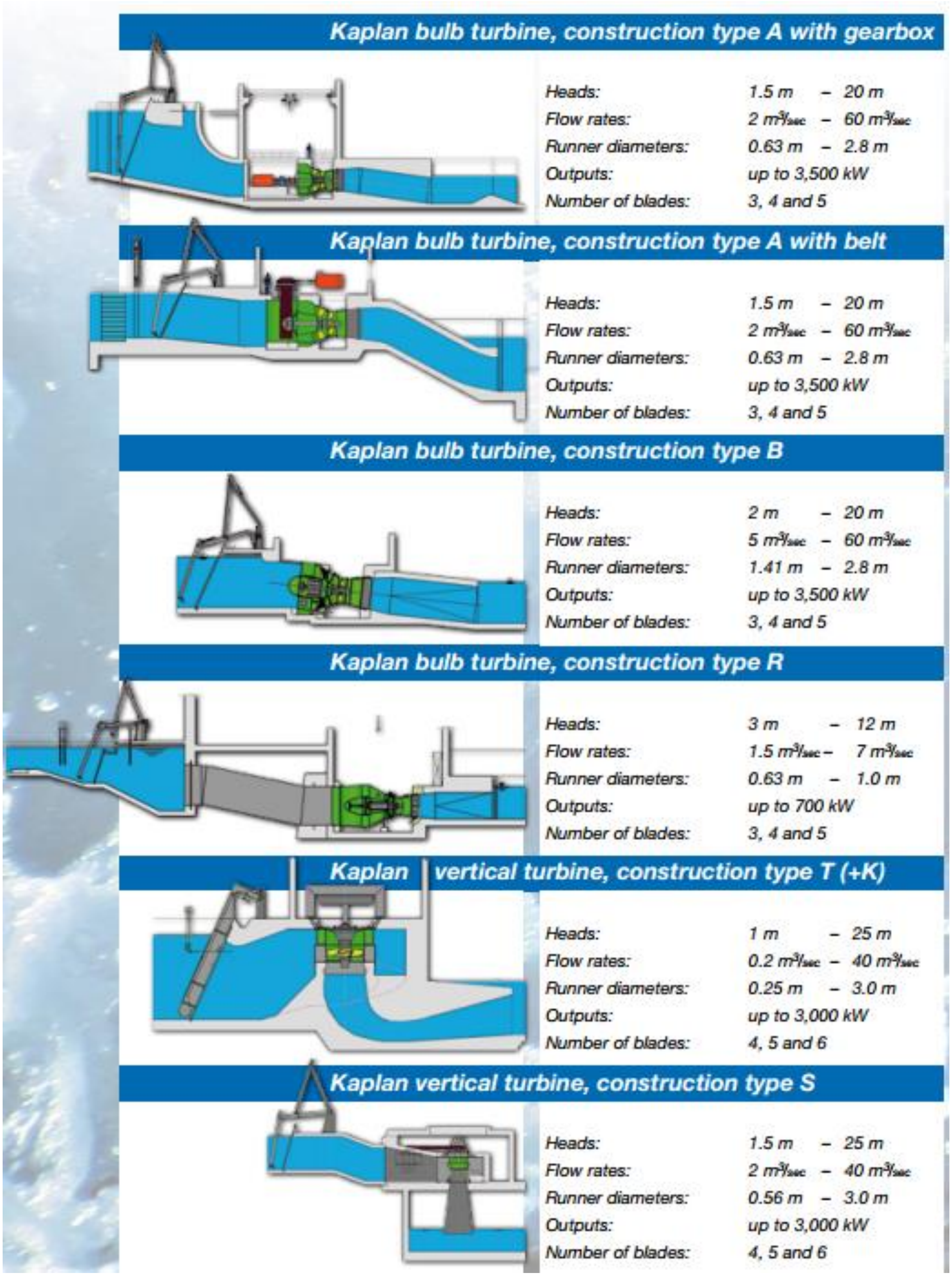


Figure 2: general arrangement of typical Kaplan turbines (Ingram 2007)

The Kaplan Bulb turbine evolved from the Francis turbine, and allowed for a more efficient production of power in considerably lower head application scenarios that were not possible with the Francis turbine. Kaplan Bulb turbines rotate very quickly, up to nearly four hundred fifty revolutions per minute. Larger Kaplan turbines have the potential to create enough hydroelectric power to power up to five million households a year. This is the equivalent of twenty million barrels of oil, or nearly ten million metric tons of carbon dioxide emissions. Together with its variable head, Kaplan turbine can produce and output that ranges from a few KW up to 230 Megawatts.



Kaplan bulb turbine, construction type A with gearbox

Heads:	1.5 m – 20 m
Flow rates:	2 m^3/sec – 60 m^3/sec
Runner diameters:	0.63 m – 2.8 m
Outputs:	up to 3,500 kW
Number of blades:	3, 4 and 5

Kaplan bulb turbine, construction type A with belt

Heads:	1.5 m – 20 m
Flow rates:	2 m^3/sec – 60 m^3/sec
Runner diameters:	0.63 m – 2.8 m
Outputs:	up to 3,500 kW
Number of blades:	3, 4 and 5

Kaplan bulb turbine, construction type B

Heads:	2 m – 20 m
Flow rates:	5 m^3/sec – 60 m^3/sec
Runner diameters:	1.41 m – 2.8 m
Outputs:	up to 3,500 kW
Number of blades:	3, 4 and 5

Kaplan bulb turbine, construction type R

Heads:	3 m – 12 m
Flow rates:	1.5 m^3/sec – 7 m^3/sec
Runner diameters:	0.63 m – 1.0 m
Outputs:	up to 700 kW
Number of blades:	3, 4 and 5

Kaplan vertical turbine, construction type T (+K)

Heads:	1 m – 25 m
Flow rates:	0.2 m^3/sec – 40 m^3/sec
Runner diameters:	0.25 m – 3.0 m
Outputs:	up to 3,000 kW
Number of blades:	4, 5 and 6

Kaplan vertical turbine, construction type S

Heads:	1.5 m – 25 m
Flow rates:	2 m^3/sec – 40 m^3/sec
Runner diameters:	0.56 m – 3.0 m
Outputs:	up to 3,000 kW
Number of blades:	4, 5 and 6

Figure 3: different configurations of small scale Kaplan Turbines (Ossberger)

Mechanism

The Kaplan turbine is a propeller type turbine and it is the most widely used among many variations of the Kaplan Turbine such as Propeller, Bulbs, Pit, Straflo, S, VLH, and Tyson. The VLH turbine is very interesting because it allow fish to pass through it even during operation with a mortality of fish less than 5%. The following link shows a video of how the Kaplan turbine works in 3 dimensions:

http://www.youtube.com/watch?v=0p03UTgpnDU

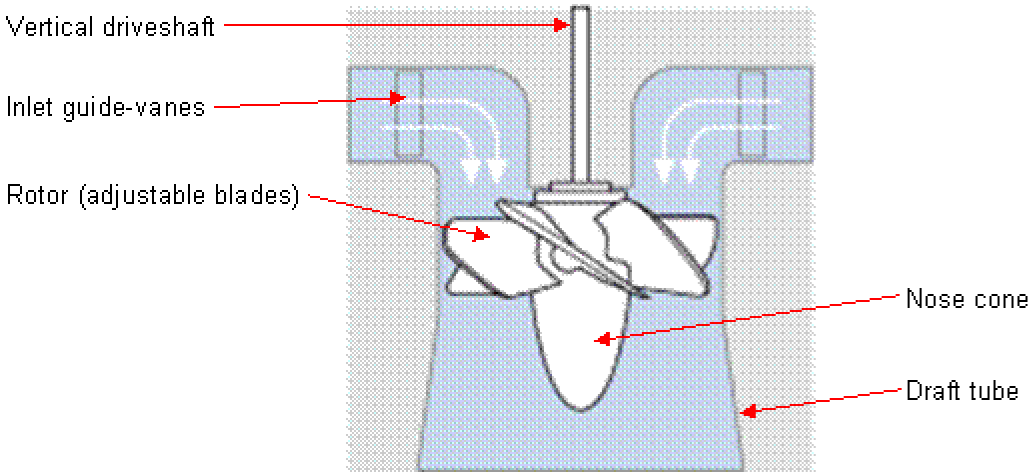


Figure 4: Basic Layout of a Kaplan Turbine (renewablesfirst.co.uk)

The Kaplan is a simple propeller with adjustable blades and the flow arrive on every side of the rotor, as shown on the figure 2 above. The inlet guide vanes can be on position open or close to controlled the amount of water supply in the turbine. The inlet guide vanes also induce the water to turn before the blades to be more efficient . The fact that we can controlled the water entry, enable to have a wide operating discharge and so production of electricity. The nose of the turbine is carefully designed to reduce the losses as long as the geometry of the pipe at the exit to decrease the pressure of water and so extracted all possible energy available. The blades of the turbine are adjustable as a function of flow velocity, which allow a wide range of discharge, as long as the number of blades (see Figure 5).

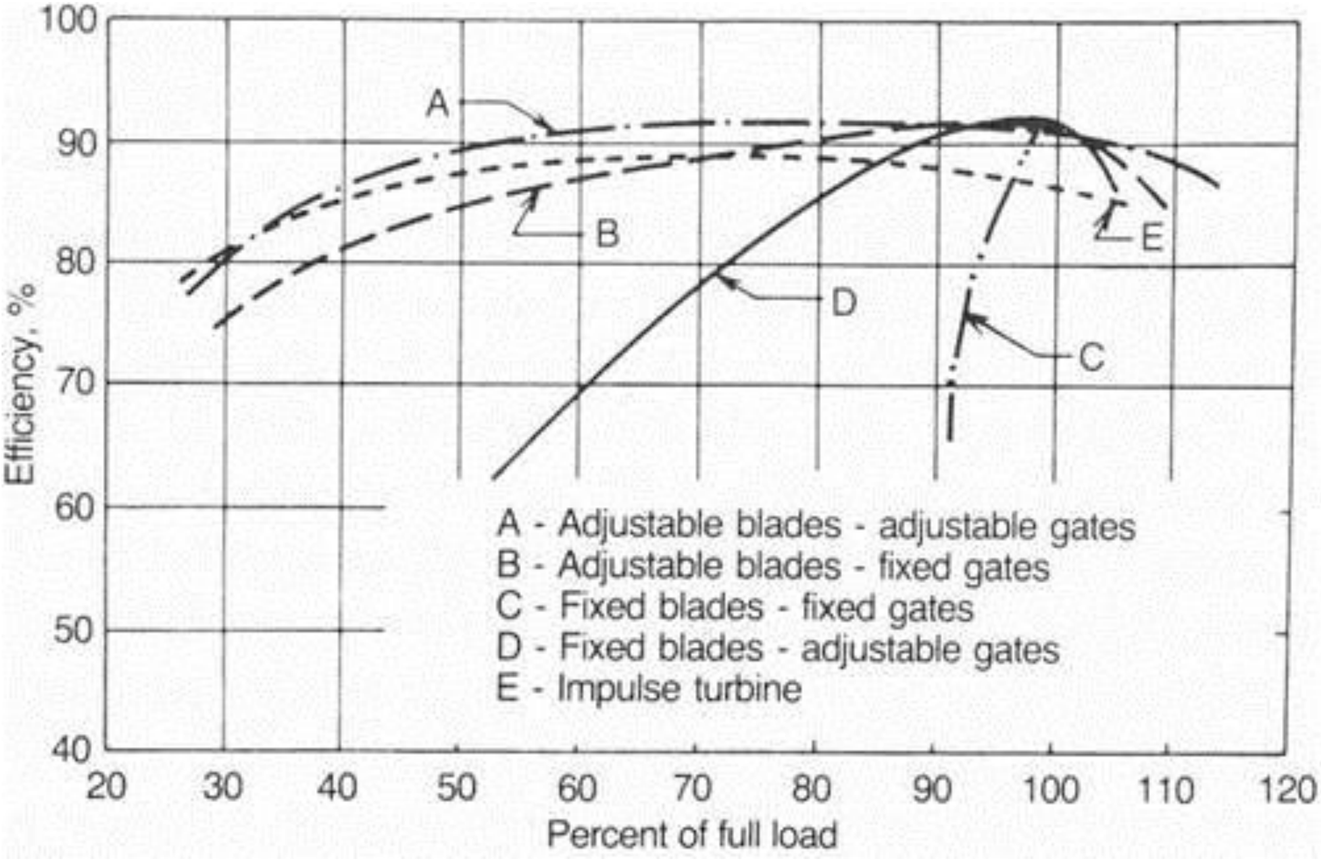


Figure 5: Efficiency of Different Kaplan Turbines

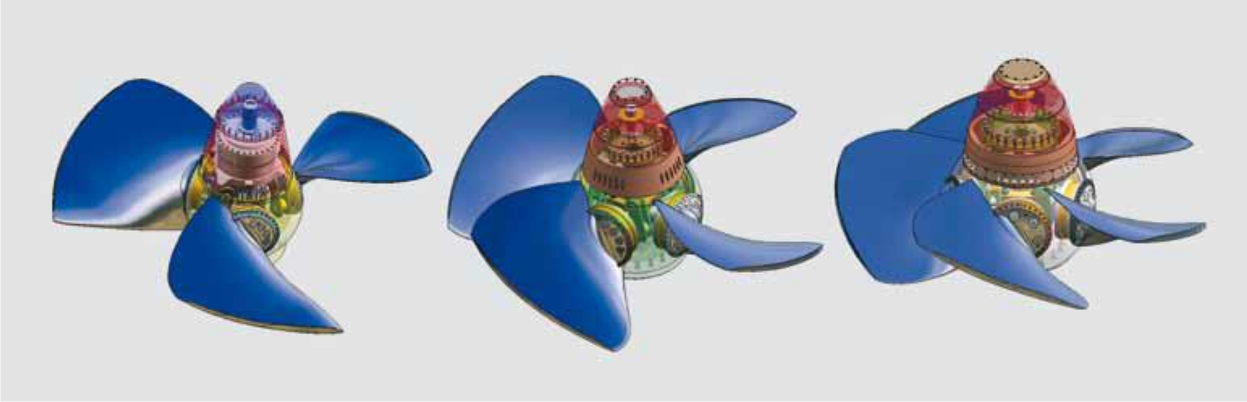


Figure 6: Kaplan Turbine with different number of blades 3, 4, 5

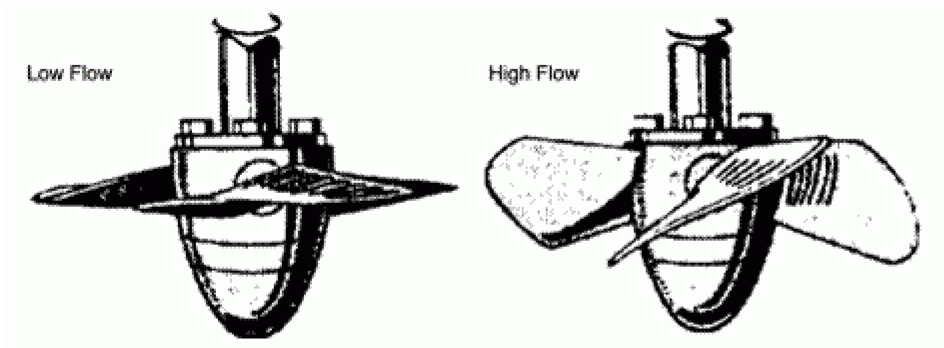
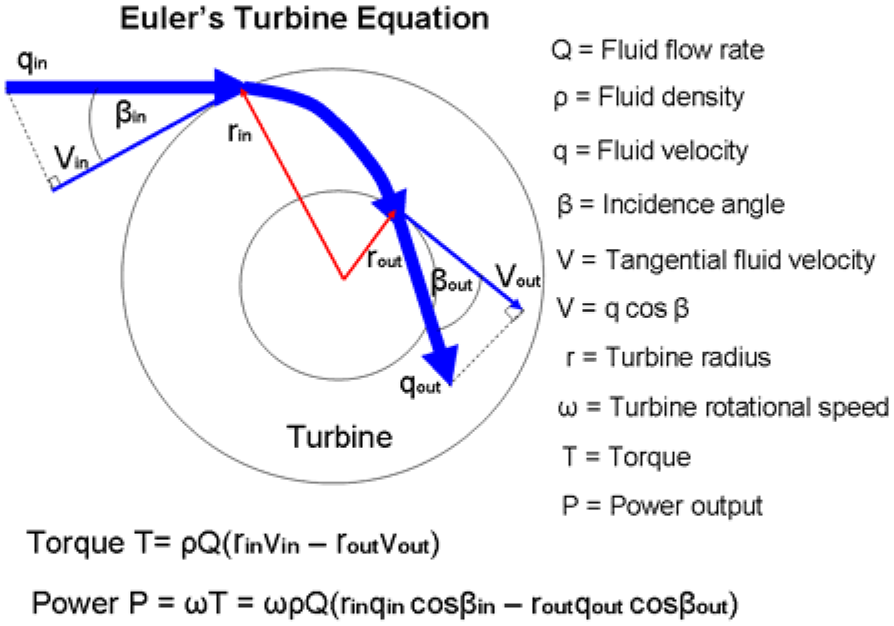


Figure 7: Rotor Blades of the Kaplan Turbine can be adjusted for flow (renewablesfirst.co.uk)

As a propeller turbine that generates electricity by reaction forces, the Kaplan Turbine power output follows the Euler’s Turbine Equation as described in Figure 8



Q = Fluid flow rate
ρ = Fluid density
q = Fluid velocity
β = Incidence angle
V = Tangential fluid velocity
$V = q \cos \beta$
r = Turbine radius
ω = Turbine rotational speed
T = Torque
P = Power output

Torque $T = \rho Q(r_{in}V_{in} - r_{out}V_{out})$

Power $P = \omega T = \omega \rho Q(r_{in}q_{in} \cos\beta_{in} - r_{out}q_{out} \cos\beta_{out})$

Figure 8: Euler's Turbine Equation

Specific Uses

The Kaplan turbine is mainly used in electrical power production all around the world where the conditions vary but usually where there is low hydraulic head. This type of turbine can produce a lot of energy with low head of water (10 to 70 m) because the diameter of the turbine are between 0.8 and 11 meters, which produce a very high discharge. In this part of the project we will talk about different use of these turbines around the world, such as in dams but also more suprisingly in tidal power stations. A tidal power station is a sort of dam that retain the water during tide. As the water moves up the hydraulic head increase between the oceon side and the other side. When the gate is open the water goes thrugh turbines (Kaplan turbines) which produce energy. Kaplan turbine are widely use in tidal power since the hydraulic head is stiil low even with high tide.

Due to its versatility and efficiency, Kaplan turbines are used in many different hydroelectric plants around the world ranging from the largest Manual Piar Hydroelectric Power Plant to many micro-hydroelectric power plants in smaller towns.

Manuel Piar Hydroelectric Power plant

The Manuel Piar Hydroelectric power plant is situated in Venezuela on the Caroni River. This project is known as the largest and most efficient Kaplan turbine in the world (see figure Z). This power plant is situated in the lower part of the river is under construction and includes ten Kaplan bulbs of 8.6 meters in diameter that will be generated 230 megawatts each with a hydraulic head of only 35 meters, the speed of the turbine is 90 rpm. These ten Kaplan bulbs obtain the world record 2012, and the total capacity of the reservoir is 1.43 million of acre ft. over 34 square miles. The spillway has a capacity of 28,750m^3/s. This hydroelectric power plant is very important because hydropower is one of the most used renewable energy in Latin America.

Figure 9: Lowering its first Kaplan Turbine at Manuel Piar Hydroelectric Power Plant (IMPSA)

Engineer Sergio Motta Dam

Figure 10 Engineer Sergio Motta Dam (Hydro Brazil)

The engineer Sergio Motta Dam was built during the 80's on the Parana River in Brazil, near Sao Paulo and cost 9 billion US dollars. It is a concrete dam of 72 ft. high and longest at 6.7 miles which contain a reservoir of 16 million acre ft. over 870 squares miles. Formerly known as the Porto Primavera Dam it includes a hydroelectric power plant that contain fourteen Kaplan turbines with a total capacity of 1,540 megawatts. These Kaplan bulbs are supplied by a gate controlled spillway. To aid with fish migration, the dam has a 1710 feet long fish ladder.

Sihwa Lake Tidal Power Station

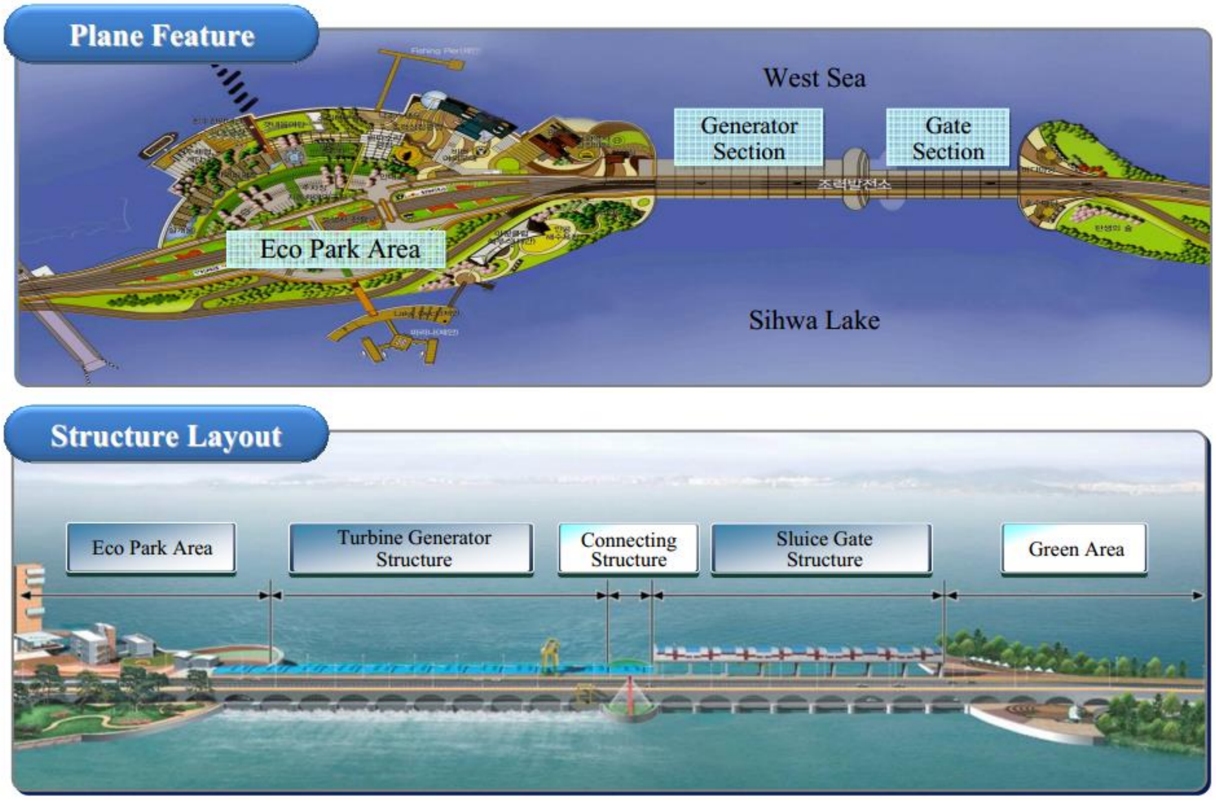


Figure 11 Sihwa Lake Tidal Power Station Design (pemsea.org)

This tidal power station is the largest one in the world situated in South Korea, on the Sihwa Lake. The construction is completed in 2011 and cost around 300 million US dollars. The power house is composed of ten Kaplan turbine types that produce a total of 254 megawatts. The tidal range is 5.6 meters with a peak in spring of 7.8 meters so the hydraulic head is very low which is ideal for Kaplan bulbs. Note that for tidal power plants water enters the storage area during high tide from West Sea to Sihwa Lake via the Sluice Gate Structure and flows out through the Generator Structure during low tide conditions to generate hydropower.

La Rance Tidal Power Station

The La Rance Tidal power station is the first to be built and second biggest tidal station in the world behind Sihwa Lake Tidal Power Station. The power is situated on the estuary of the La Rance River in France and contains 24 turbine of Kaplan type that can produce a total of 240 megawatts of electricity. The dam is 2,300 ft. long and the tidal range is 8 meters with a peak in spring of 13.5 meters so the hydraulic head is very low but ideal for the use of Kaplan Turbines. Construction was completed in 1966 at a cost of 100 million Euros.

Figure 12: La Rance at low tide and high tide (whereongoogleearth, flickr)

Pros and Cons

Pros:

- Kaplan Turbines can achieve efficiency of up to 95%.
- Can be implemented in low-head situations allowing for power plants at lower elevation.
- Varying size of turbine and output allows for micro-hydropower plants instead of large dams.
- Kaplan Turbines are relatively low cost due to the small size and low head requirements.
- Dams build with the Kaplan Turbine design produces less environmental impact because of low head requirements therefore the reservoir area would not be flooded as much as high head dams.

Cons:

- Often times, Kaplan Turbines are installed where fish migrations occur, and may potentially affect their migration patterns and survival rates.
- The high velocity of the turbine may cause leakage of oil-based lubricant into the outlet leading to pollution.
- Due to the high discharge of the turbine, the water around the turbine can reach very low pressure making the Kaplan turbine vulnerable to cavitation.

Sources & Additional Reading

---

1. Alstom Kaplan Hydro Turbines.
   Available at: http://www.alstom.com/products-services/product-catalogue/power-generation/renewable-energy/hydro-power/hydro-turbines/kaplan-hydro-turbines/
2. Barrage de la Rance.
   Available at: http://www.wyretidalenergy.com/tidal-barrage/la-rance-barrage
3. Cavitation in Hydraulic Turbines: Causes & Effects.
   Available at: http://www.brighthubengineering.com/fluid-mechanics-hydraulics/27427-cavitation-in-hydraulic-turbines-causes-and-effects/
4. Hydraulic Turbines: Kaplan Turbine.
   Available at: http://www.brighthubengineering.com/fluid-mechanics-hydraulics/27426-hydraulic-turbines-kaplan-turbine/#imgn_0
5. Hydroelectric Power.
   Available at: http://www.mpoweruk.com/hydro_power.htm
6. Hydroelectric Power Plants in Brazil.
   Available at: http://www.industcards.com/hydro-brazil-sp.htm
7. Hydropower Turbines: Kaplan Turbines.
   Available at: http://www.renewablesfirst.co.uk/hydro-learning-centre/kaplan-turbines/
8. IMPSA installed the first 232 MW Kaplan turbine at the Tocoma Hydropower Plant.
   Available at: http://www.impsa.com/en/news/SitePages/23-04-12.aspx
9. Kaplan Turbine – A Mammoth in Hydroelectricity Generation
   Available at: http://www.learnengineering.org/2013/08/kaplan-turbine-hodroelectric-power-gneration.html
10. Kaplan Turbine Working & Design.
    Available at: https://www.youtube.com/watch?v=0p03UTgpnDU
11. Kossler Kaplan Turbines.
    Available at: http://www.koessler.com/sites/default/files/produkte/Kaplan_E.pdf

12. Necker, Ashenbrenner, Moser 2009. Cavitation in a Bulb Turbine.

    Available at: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/84277/cav2009-final91.pdf?sequence=1
13. Ossberger Kaplan Turbines.

    Available at: http://hts-inc.com/images/S-160.pdf
14. Sihwa Tidal Power Project.

    Available at: http://pemsea.org/eascongress/international-conference/presentation_t4-1_kim.pdf
15. Theory of Turbo Machinery.

    Available at: http://www.lth.se/fileadmin/tpe/Kurser/Chapter_9.pdf
16. Tocoma Hydropower plant – Manuel Piar.

    Available at: http://www.impsa.com/en/downloads/HYDRO/TOCOMA.pdf
17. Voith Kaplan Turbines.

    Available at: http://voith.com/en/Broschuere-Kaplan-turbines_screen-doppelt.pdf
18. Very Simple Kaplan Design.

    Available at: http://community.dur.ac.uk/g.l.ingram/download/kaplandesign.pdf