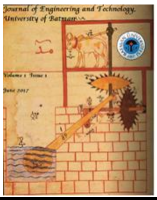

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A review on alternative hydropower production methods

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ABSTRACT

Increasing energy prices, exponentially growing power need and detrimental effects of conventional fossil fuel consumption has lead scientists and engineers to find alternative and clean ways of energy production. Hydropower is one of the clean and renewable energy extraction methods providing very high potential of energy with considerably high predictability. Conventional hydroelectric plants (HEPP) are quite old technique of energy production covering about one fifth of electricity need of the world. Hydroelectric energy is site specific and most of the suitable locations for HEPPs are already exploited. Also the conventional technology have high amount of civil works together with serious environmental impacts. In this study, both conventional and alternative hydropower production methods were reviewed with special emphasize on modern technology and processes. Run-of-river hydropower production schemes, tidal energy and other in-stream energy conversion systems, wave energy technologies, ocean thermal and osmotic power stations were analyzed. The methodology and device mechanisms were investigated.

1. Introduction

Water is the most important natural resource for human being. All living organisms need water for their vital activities. Life would not be possible on the earth without water. Hydropower is basically the power extracted from the moving water. The sun gives energy and evaporates a certain amount of water from the surface of oceans, rivers, reservoirs and other open channels. Huge amount of potential energy is given to the evaporated water and great mass of water is raised to the atmosphere by the effect of the sun. The same amount of water returns to the earth as precipitation either with rain and snow. The precipitation mainly occurs at the mountainous regions. Rain and melting snow generates streamflow with the effect of the regional slopes. The river streams provide an excellent source of power for human being which is harnessed by classical hydroelectric power plants (HEPP).

On the other hand, very effective winds are produced by the temperature and pressure differences at the atmosphere. The winds drive the marine currents and waves which is another indirect form of solar energy. This energy can be extracted by modern devices. Similarly, tidal currents are generated by the gravitational attraction between the earth moon and the sun. Important amount of energy is given to the

surface water by the indirect effect of the sun. Consequently, almost all natural processes are driven by the effect of the sun. The energy that we use is an indirect form of the sun's energy [1-3].
The history of extracting mechanical power from water movements is very old. One of the first applications of hydropower harnessing was implemented by the ancient Egyptians. They generated a shaft power (rotational energy) by waterwheels in order to move water to irrigate their grains and other crops. Then the Ancient Greeks, Chinese and Romans were used the similar techniques and they built huge waterwheels [4]. Massive dams were constructed in India at 1600's for irrigation and drinking purposes. The very modern hydroelectric power plant is built on Fox River (USA), in 1882 in order to provide a factory's own electricity demand. Then, bigger hydroelectric power plants (HEPP) were built at the different places on the earth [1].

About 70 % of earth's surface is covered by water making the hydropower to be the largest, cheapest and most common source of energy. Very small amount of this energy is exploited by the today's techniques. Technological developments will increase feasibility of energy extraction from oceans.

Four different types of energy could be harnessed from the water spread around the world. These are;

1. Kinetic energy in rivers, waves and marine currents,
2. Potential energy in rivers, waterfalls, tides and waves,
3. Solar energy that is stored as heat at the surface of oceans,
4. Osmose energy due to concentration difference of saline ocean water.
5.

In this study, the classical and modern hydro-energy production methods were reviewed. The scientific background, technological developments and other technical details of these methods were analyzed. An up to date review was provided.

2. Classical hydroelectric power plants

The main energy converters at classical hydroelectric power plants are turbines that are working with a suitable water head. The river is trapped with an obstacle which is called a barrage. Streamflow's water is accumulated at a suitable region and a huge reservoir is generated. The reservoir provides a water head in the form of potential energy between the free surface and turbine's elevation. This energy is converted into mechanical energy in turbines and a shaft power is provided. Then, it is converted into electrical energy by means of generators. Different types of turbines are used for different water elevations. All dams and small hydroelectric power plants employ these principles in order to generate power.

Hydropower provides the largest and most common source of alternative energy. Globally more than 150 countries generate hydroelectric power. Some of these nations produce their essential amount of electricity need, totally from hydropower [5]. Dams are constructed for some other purposes apart from electricity generation such as; irrigation, domestic use, flood control. Globally, around 50,000 dams are constructed for these aims.

In 2016, the total worldwide installed hydropower capacity is reached at 1,064 GW which corresponds 71% of all renewable electricity production and % 16.4 of total electricity generation (from all resources). Around quarter of the world's installed hydroelectric capacity is exploited in China itself. After China, USA, Brazil and Canada are the largest hydropower generating countries. The remaining (not utilized) hydroelectric energy potential of the world is estimated to be 10,000 TWh/year. The world's largest hydropower station is Three Gorges Dam in China which is actually constructed for flood control purpose. The installed capacity of Three Gorges Dam is 22.5 GW and around 88.2 TWh of electricity is generated each year. Turkey's total installed hydropower capacity is 25,886 MW with estimated 66,900 GWh/year electric energy in 2015. Turkey is already exploited 27 % of its hydropower potential. The total hydropower potential of Turkey is predicted to be around 216,000 GWh/year [6].

Together with high amount of energy production, hydropower could have very serious environmental impacts. The biggest environmental disadvantage of conventional HEPP's is inundation of very large regions. Generally, river beds are considered as very fertile lands which are rich in terms of alluvial and sediments. The sediments are trapped with barrage and collapse at the dam's reservoirs. The sediment accumulation is the most important risk which restricts the life-span of a classical HEPP. On the other hand, generally dam reservoirs are natural places that are suitable for human occupation. Reservoir construction forces people to move and migrate from their original lands to some other places. This damages the socio-cultural links together with causing high amount of money to be spent by countries for immigration activities. Similarly, dam's reservoirs could be very important historical areas. The reservoir construction could destruct historical artifacts at that region. If this is considered together with the short life span of the dams, it may not be effective because of the long term problems. Together with indirect environmental impacts, the direct effects of dam constructions should also be considered. Wetlands are often providing accommodation for high diversity ecosystems. The natural ecosystem at the proposed reservoir region could be detrimentally affected. Also, the chemical materials and turbine parts could injure water ecosystem [7].

Consequently, greater construction activities cause greater damages to the environment. The environmental, historical and socio-cultural damages should be investigated and analyzed in detail. Taking the long term risks for relatively very short term profits could not be advantageous for future generations.

The technological developments unveiled new, more harmless and alternative ways of energy production from water streams and waves. Although the classical HEPPs are considered as renewable energy systems, some alternative ways of energy generation should be used to protect future generations and to provide sufficient power. The rest of the present study is based on alternative hydropower production approaches.

3. Alternative ways of hydropower production methods

3.1. Run-of-river hydropower production

These are small scale hydroelectric power plants without reservoirs. Sometimes very limited amount of water could be accumulated using a weir. Mainly, a certain amount of water is diverted from the main stream at a sloped region. A weir is used to divert water and to regulate the suitable elevation. The water is directed to a turbine using a penstock. Water head and discharge is converted into mechanical energy with a relatively small scale turbine. Electric energy is generated as the same principles as classical HEPP's. The tail water is again connected to the main channel.

The run-of-river schemes are regional and smaller scale power plants. Environmental impacts are very limited compared to classical HEPP's. Some modern types of run-of-river schemes are designed to provide fish passage through the system without harming fısh habitats and their natural activities. Researches about the environmental impacts of the run-of-river stations are limited [8] and more discussions should be provided for better illustration of the natural damages.
Run-of-river schemes are less expensive requiring less technical efforts for construction. The energy prices per kWh or energy is higher relative to the conventional hydroelectric power plants [9]. The

overall water to wire efficiency of run-of river hydropower plants are estimated to be between 0.5 and 0.7 [10;7].

The power of a run-of-river plant can be calculated as Equation 1.

$$P = \rho g Q H_o \eta \quad (1)$$

where; P is the total installed power of the plant (watt); ρ is density of water (1000 kg/m^3); g is the gravitational acceleration coefficient (9.81 m/s^2); Q is the discharge of water (m^3/s); H_o is the overall head of water (m) and η is the total efficiency of the power plant.

4. Tidal dams

The ocean water is affected from the gravitational attraction between the earth, moon and the sun. The surface water elevation at shores especially at specific locations on the earth rises and falls under the effect of the gravitational forces. If the movement of water is toward to the shore region, the event is called as flood. The reverse process is called as ebb tide [2]. The time difference between one flood and ebb tide is around 6 hours. The tidal height varies at different regions on the earth according to the bathymetry and physical structure of the ocean bed. The water elevation difference during flood and ebb cycles becomes significant at some specific locations. The maximum tidal range is obtained at Bay of Fundy (Canada) reaching up to 20 meters. Some regions experience the semidiurnal tides which occur twice a day. Similarly diurnal tides are observed once a day[11].

One complete cycle of the moon around the earth is exactly 25 hours and 50 minutes. Therefore the duration between high and low tides is half of this time. Spring tides provide highest tidal height with the combined effect of the moon and sun with the period of 14 days. The lowest tidal heights occur at quarter phases and the event called as neap tides [2;11].

The tidal energy could be harnessed via two ways which are very similar to the generational HEPPs. These are hydrostatic and hydrokinetic approaches. The hydrokinetic approach is based on capturing directly the energy of tidal streams without impounding (Section 3.3). Tidal barrages are the oldest technique of harnessing tidal energy. During the high tide, the potential energy of the elevating water is stored. During the low tide, the accumulated water is released and this energy is converted into kinetic energy through the turbines. The tidal dams are said to be efficient when the tidal range is greater than 5 meters [7]. The turbines can be run bi-directionally during flood and ebb processes providing extra energy.

To date, four big scale tidal plants are available under the operation. These are La Rance (France), Kislaya Guba (Russia), Annapolis (Canada) and Jiangxia (China) having installed power respectively as; 240, 0.4, 18 and 3.9 MWs [12]. The height of the mean tide at La Rance dam which is found at Nort-West France reaches up to 13.55 meters which makes this dam to have highest installed power. La Rance dam was constructed in 1960 on an area of 22 km^2. 24 bi-directional bulb turbines each having 10 MW capacity have been installed. The net output is around 480 GWh of energy each year [13].

The average power of a tidal event is given as [11];

$$P_{avg} = \frac{\rho g A h^2}{2T} \tag{2}$$

where, T is the tidal period, A is the surface area, h is the tidal height.

5. Hydrokinetic energy conversion technologies

Hydrokinetic energy technology is related harnessing the energy of flowing water. Hydrokinetic turbines are very similar to submerged wind turbines. This type of turbines converts in-stream kinetic energy of water into directly electric energy. These systems do not depend on the potential energy and there is no need to construct a reservoir to store the water. Therefore hydrokinetic systems require minimum amount of civil works.

To date the power capacity of hydrokinetic turbines which are under the operation is insignificant comparing to the conventional hydroelectric power plants. The technical details of the most popular hydrokinetic turbines are given in Table 1.

Table 1. Technical details of most popular hydrokinetic technologies [11]

Turbine	Rotor diameter (m)	Rated power (kW)	Rated velocity (m/s)	Cut-in speed (m/s)	# of blades
SeaGen	18	1200	3.4	0.7	2
Verdant Power	5	35	2.2	0.7	3
Lucid Energy	1,2,3	40-150-360	4.5	0.5	Multi
UEK (Underwater Electric Kite)	4	400	3	1.54	Multi
Tigris-27H	3	27	2.7	0.7	3

The SeaGen project is known as the highest capacity hydrokinetic turbine project to date. A tower of 21 m supports two bi-directional two bladed turbines each have 600 MW of rated power. The blade diameter is 18 meters. The tower facilitates providing maintenance and adjustments raising the system [16]. The other most famous hydrokinetic turbine developers are Verdant Power and Lucid Energy companies.

The in-stream hydrokinetic energy converters deliver the energy with relatively lower efficiencies. The theoretical Betz limit is the most important restriction of the technology. Any un-ducted in-stream energy converter cannot exceed 59 % efficiency, theoretically. This limitation can be overcome by building a duct around the turbine blades which is also called as augmentation.

Different configurations of hydrokinetic turbines are available in the literature. The technology is classified according to the orientation of blades' axis and design of the blades as horizontal axis, vertical axis, ducted and helical turbines. The most common and efficient types of hydrokinetic turbines have horizontal axis mechanism. The helical turbines are designed by twisting the whole system around the horizontal or vertical shaft.

The hydrokinetic turbines are produces electricity, mainly based on the aerodynamic forces generated on the blades. The lift and drag forces and pitching moment are yielded around the blade. The lift force of each blade section forces blade to rotate around an axis. The optimum angle of the blades and the pitch angle are different for each blade section to maintain the suitable angle of attack. The hydrokinetic turbines are designed by using Blade Element Momentum (BEM) theory, one dimensional disk theory and other methodologies which are adapted from the ship propellers and wind turbines.

The hydrodynamic forces around the hydrokinetic turbines are the main inputs for structural design and blade mechanisms. Different types of regulation mechanisms are used to protect the turbine blades from off-design loads. These are stall regulation and pitch regulation mechanisms. High hydrodynamic loads, the harsh marine environment, debris and corrosion problems are among the major drawbacks of the technology. The illustration of blade sections and aerodynamic forces are given in Figure 1.

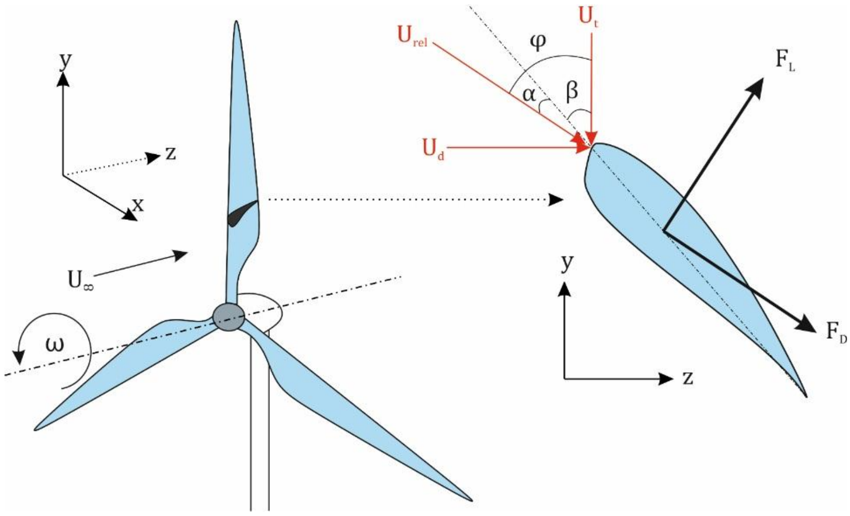

Figure 1. Illustration of the aerodynamic forces around hydrokinetic turbines

(*w* is the angular velocity; U_{rel}, U_t and U_d are the relative velocity, tangential velocity and free stream velocity vectors, respectively; F_L and F_D are lift and drag forces; respectively)

6. Wave energy conversion

Wave movement is a stochastic process due to diffraction and radiation [14]. Therefore, theory is mainly device based. The wave energy conversion technology is at its infancy and need to be better developed. The technologies in the literature can be divided into three classes. These are; oscillating water bodies, overtopping devices and wave activated bodies.

Oscillating water bodies uses a submerged part providing a chamber that allow water surface to be oscillated. While waves are moved, hydrodynamic and hydrostatic forces rises and falls the water level inside the chamber. The movement of the water elevation compresses and decompresses air situated above the water. The air movement is converted into electric energy using a suitable type of turbine. Generally a Wells turbine is used which works bi-directionally at the compression and decompression stages.

Overtopping devices employ the elevation difference of incoming wave to produce power. The incoming wave is filled into a chamber and returns to the sea. The water head is transformed to kinetic energy inside a pipe and this energy is extracted by a suitable turbine.

There are various different types of wave activated energy converters. This technology converts the wave oscillations into regular movements and then energy is produced with suitable converters. Limpet (oscillating water column), wave dragon (overtopping device, [17]) and Pelamis (wave activated body) are among the most famous wave energy converters [11].

7. Osmotic power

The fluid molecules move from the less concentrated regions toward the high concentrated regions which is known as the diffusion. The concentration difference can be created in the nature where fresh water is poured into the ocean. The freshwater has low salt concentration and ocean water has high concentration. If both fluids are separated with a semi-permeable membrane, the concentration difference drives the fluids and provides a water head difference. This elevation difference is concerted into electrical energy using suitable turbines. The process is called pressure retarded osmosis (PRO).

This is extremely new technology where the energy potential is relatively less comparing to the other hydropower conversion technologies. The efficiency of the converters is mainly based on the membrane technology. Statkraft Company at Norway operated the first osmotic power plant in 2009. The power output is reported to be 1 W/m^2. The total installed power of the factory is known as 2 kW with a total membrane area of 2000 m^2.

8. Ocean thermal power generation

Sun is the ultimate source of energy. The oceans receive a great amount of solar energy covering around 71 % of the earth's surface. The temperature difference can reach up to 25 °C between the surface and at 1000 m depth of the ocean. This heat difference could provide high amount of energy if the suitable device and technologies are used. The energy potential is not site specific as conventional hydroelectric power plants and homogeneously distributed around the world. The distribution of the energy to extremely large area is a major drawback of the process. Only 200 kW power could be supplied from 1 km^2 of the ocean. Increasing energy prices and development on the more efficient technologies could increase the feasibility of the technology [11].

One of the first ocean thermal energy conversion plants is installed at Hawaii with a rated power of 103 kW. The installed capacity of the technology is around 1 MW over the world. Some high capacity ocean thermal energy plants are still at the project stage [15].

9. Conclusion

Majority of the sites which are suitable for classical hydropower production are already occupied. Considering the increasing energy need, scientists and engineers are trying to find alternative ways of energy production. Some of the alternative methods are still their infancy such as hydrokinetic and wave energy converters and osmotic power and ocean thermal renewables. The technical feasibilities of these devices are relatively low comparing to the classical HEPPs. Technological developments could facilitate to increase the efficiency of alternative methods of energy extraction. In-stream hydrokinetic and wave energy technologies seem to achieve the feasibility limits. These technologies are at the deployment phases and important companies are already making investments especially on hydrokinetic energy devices. The hydrokinetic technology could be the solution of delivering power to off-grid and remote regions where the electricity could not be supplied. The osmotic power and ocean thermal energy methods seem to be quite unfeasible with today's technology. Consequently more detailed scientific analyses are needed in order to increase efficiency and to understand natural impacts of alternative methods to overcome future energy and environmental crises.

10. References

[1]. Cruden, G. (2005). *Energy alternatives*. Thomson Gale.
[2]. Toossi, R., (2009). *Energy and the environment*. Los Angeles, CA: VerVe Publishers
[3]. Quaschning, V. (2010). *Renewable energy and climate change*. (Hedy Jourdan, Trans.) Berlin University of Applied Systems HTV, Germany: Wiley
[4]. Schlager N. and Weisblatt J. (2006). *Alternative energy*. Vol.3. Thomson Gale
[5]. Yuksek O., Komurcu, M.I., Yuksel, I., and Kaygusuz, K., (2006). The role of hydropower in meeting Turkey's electricity demand. *Energy Policy*, 34, 3093-3103
[6]. WEC (World Energy Council), 2016. World Energy Resources, Hydropower 2016.

[7]. Muratoglu A. (2011). Assessment of Tigris River hydropower potential. M.Sc. thesis. University of Gaziantep.

[8]. Bilotta GS, Burnside NG, Gray JC, Orr HG. (2016). The effects of run-of-river hydroelectric power schemes on fish community composition in temprete streams and rivers. Public Library of Science One. 2016;11(5).

[9]. Cey E, Goodfellow L, Hanania J, Stenhouse k, Donev J. Run-of-the-river systems. (2017) Web page. University of Calgary. Available at: http://energyeducation.ca/encyclopedia/Run-of-the-river_systems

[10]. NRC (Natural Resources Canada). (2004), Micro hydropower systems. A buyer's guide.

[11]. Muratoglu A, Yuce MI, (2016). Advances in hydropower production: marine energy conversion. 12th International Congress on Advances in Civil Engineering (ACE 2016). 21-23 September 2016, Istanbul, TURKEY.

[12]. Gorlov, A.M. Tidal Energy, Academic Press, Boston, 2001.

[13]. Rourke F., Boyle F. and Reynolds A, Tidal energy update 2009, Applied Energy, 87 (2), 2010.

[14]. Bahaj AS. (2011). Generating electricity from the oceans. Renewable Sustainable Energy Reviews, Vol. 15, pp. 3399–416.

[15]. IRENA (International Renewable Energy Agency). (2014). Ocean thermal energy conversion technology brief. Available at: www.irena.org.

[16]. Yuce MI, Muratoglu A. (2015). Hydrokinetic energy conversion systems: A technology status review. Renewable and Sustainable Energy Reviews; 43, 72–82. Doi: 10.1016/j.rser.2014.10.037

[17]. 1Wave Dragon. (2016). Available at: http://www.wavedragon.net/index.php?option=com_content&task=view&id=6