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Review of Various Designs and Development in Hydropower Turbines

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Abstract**—**The growth of population, rising fossil fuel prices (limited and decreasing day by day), pollution problem due to use of fossil fuels and increasing electrical demand are important factors that encourage the use of green and renewable energy technologies. Among the different renewable energy technologies, hydro power generation (large and small scale) is the prime choice in terms of contribution to the world's electricity generation by using water current turbines. Currently, researchers mainly focused on design and development of different kind of turbines to capture hydropower to generate electricity as clean and reliable energy. This paper is a review of the status of research on water current turbines carried out to generate electricity from hydrokinetic energy especially in places where there is no electricity, but there is access to flowing water.

Keywords**—**Turbines, Renewable Energy, Hydropower.

I. Introduction

NOWADAYS, Utilization of electrical energy has an important role in economic growth and improvement of people's living but the excessive usage of fossil fuels to generate electricity causes environmental pollution, greenhouse effect, CO2 emissions; not to mention that fossil fuel resources are depleting. Therefore, the reduction of using fossil fuels is urgent and replacing them with ideal energy source (an ideal energy source should be renewable and have minimal effects on environment [1]) is essential to provide a livable and unpolluted environment for next generations [2].

Briefly, Climate changing, electrical demands, rising diesel fuel prices, as well as fossil fuel-based energy is limited and in fact is depleting [3], are subjects to use of renewable technologies.

There are different kinds of renewable technologies, such as biomass, wind, solar, hydro and geo thermal, which are clean and reliable to reduce greenhouse gas emission that leads to global warming, while saving money and creating jobs. Among different renewable energy technologies, hydro power generation (large and small scale) is the prime choice in term of contribution to the world's electricity generation [4], [5].

Also, it has been shown that one-third of the world's population does not have electricity, but they have access to water [6].

Hydrokinetic energy may be generated from waves, tides, ocean currents, and the natural flow of water in rivers In addition to these, other resources include manmade channels, irrigation canals, industrial outflows or from current of collecting water after rainfall which can be used to turn water current turbines to produce hydrokinetic electrical energy [7]-[9].

The type of turbine depends on the flow type, velocity and desired output of the system can be individually selected [10] which there are two main types of hydrokinetic turbines: horizontal and vertical axes. Vertical axis current turbines include in-plane axis, Squirrel cage Darrieus, H-Darrieus, Darrieus, Gorlov, and Savonius. The H-Darrieus is known to be more efficient than other types due to arm and it can be considered as a worthwhile option for hydro applications [11], [12].

Today, turbines are under progressive development to increase torque and efficiency so that they will be usable for low speed velocity and can provide higher torque and efficiency to turn the generator and increase output power with lowest force [13], [14].

This paper presents a review about statues of water current turbines carried out using hydro kinetic energy in large or small scale to generate electricity, which is clean and reliable to reduce greenhouse gas emission while saving cost.

II. Renewable Energy Potential

Increasing energy demand, increasing population, changing consumer habits, diminishing fossil resources and their environmentally harmful effects and economic problems require usage of diverse and renewable energy sources. World energy consumption and future forecasts are presented in Fig. 1, while the world net electricity generation is shown in Fig. 2.

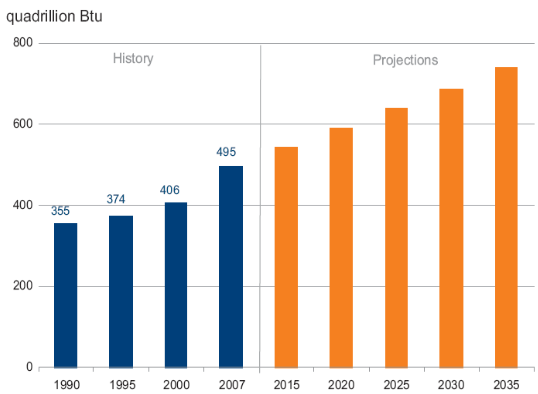

Fig. 1 World market energy consumption 1990-2035

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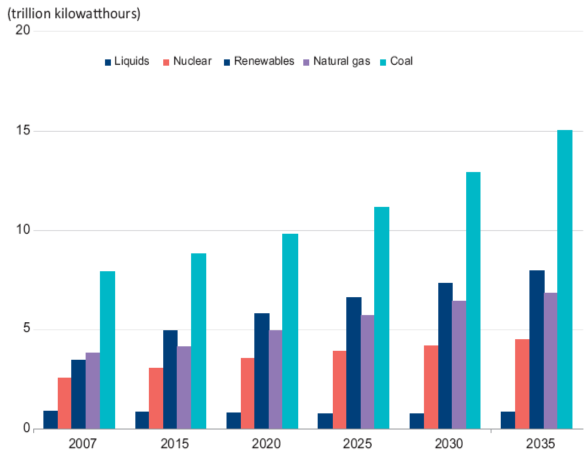


Fig. 2 World net electricity generation by fuel 1990-2035

Expectation of world renewable energy generation is given in Fig. 3. It is considerable, due to continuous available of hydrokinetic energy source, it is the most promising and suitable renewable energy among others. Hydrokinetic energy capacity forecast is presented in Fig. 4 [15].

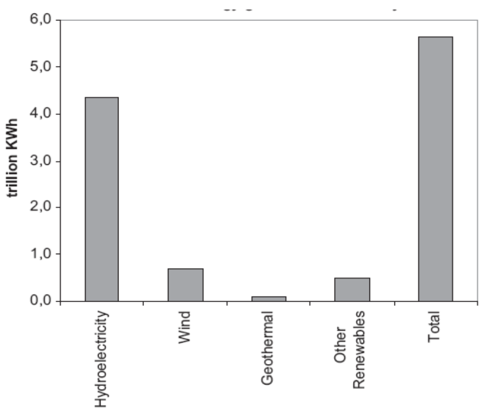


Fig. 3 World renewable energy generation in 2020 by source

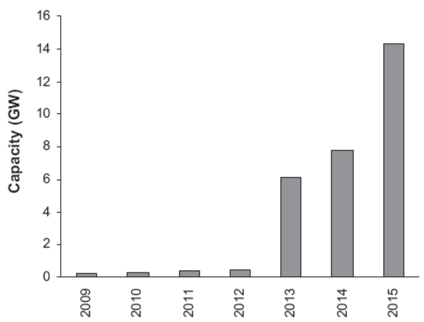


Fig. 4 Hydrokinetic energy capacity forecast 2009-2015

Considering the electricity demand in future and fossil fuels which have a lot of negative effect on environment, it is proper to use renewable energy instead of fossil fuels. As referred from the figure, hydropower is more suitable among other renewable energy. Hydropower can be generated by using different kind of turbines, so it is important to focus on the design and development of turbines to increase efficiency to generate more electricity for future generations.

III. Hydrokinetic Technology

Hydrokinetic energy can be generated from ocean, river or any water stream. Hydrokinetic or water current turbines, produce electricity directly from the flowing water in a river or a stream. The turbine blades would turn the generator and capture the energy of the water flow [16].

Conventional hydropower generation is done by building dams and the energy of falling water, running the turbine to generate electricity. Hydropower generation has negative environmental effect and is costly, but the new category of hydro power energy uses kinetic energy of stream instead of potential energy.

It is considerable that hydrokinetic turbine has a lot of similarities with wind turbine in terms of the physical principles of operation, electrical hardware, and variable speed capability for optimal energy extraction [17]. However, water is almost 800 times denser than air; therefore, hydrokinetic turbines are more efficient than wind turbine even at low speed [18], [19].

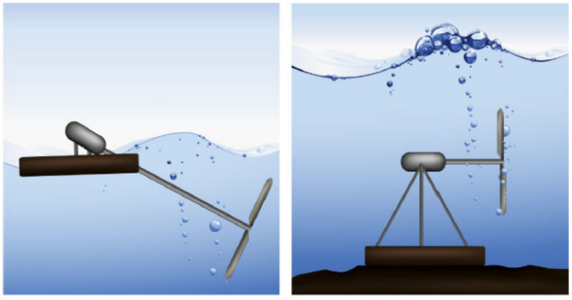
A. Turbines

There are two main configurations for turbines: horizontal (axial-flow) and vertical axis turbines; both are similar to those used for wind turbines.

The alignment of rotor axes with respect to the water flow can be categorized into two: one category classifies turbines into two types: horizontal axis and cross flow turbine whose cross flow is divided into two types of in-plan and vertical axis [12] and another category classifies turbines into three types: horizontal axis, vertical axis and cross flow turbine [20]. Axial-flow (alternatively called horizontal axis) turbines have axes parallel to the fluid flow and employ propeller type rotors. Various arrangements of axial-flow turbines are shown in Fig. 5. Inclined axis turbines (a) have mostly been studied for small river energy converters. Other axial-flow turbines (b, c and d) are mainly used for the extraction of ocean energy, and are similar to wind turbines in terms of design and structural point of view [10], [20], [12], [21].

Meanwhile, turbines with rigid mooring structures require the generator unit to be placed near the riverbed or seafloor for more reports and information about rigidly moored tidal/river turbines, which can be referred in [22], [23].

Horizontal axis rotors with a buoyant mooring mechanism may allow a non-submerged generator to be placed closer to the water surface. Information on submerged generator systems and non-submerged types can be found in [24], [25] respectively.



(a) Inclined axis (b) Rigid Mooring

(c) Non-submerged Generator (d) Submerged Generator

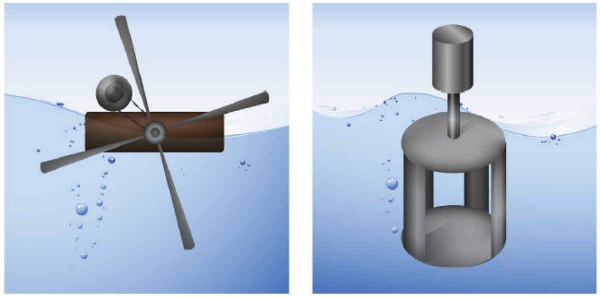
Fig. 5 Horizontal axis turbines

The cross-flow turbines as shown in Fig. 6 have rotor axes which are orthogonal to the water flow but parallel to the water surface. They can be divided into vertical axis (axis vertical to water plane) and in-plane axis (axis on the horizontal plane of the water surface). The in-plane turbines (a) are generally drag based devices and said to be less efficient than their lift-based counterparts. In the vertical axis domain (b, c, d, e and f), Darrieus type turbines are common in river energy applications [11]. Straight bladed Darrieus turbines (H-type or Squirrel Cage type) can be considered as a viable option for hydro applications and they are very common [11], [12].

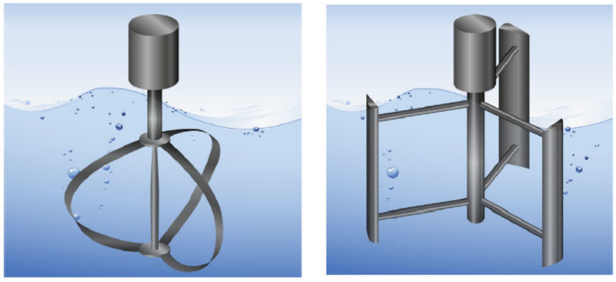
Publications such as [26]-[28] included information about design, operational and performance issues regarding straight bladed Darrieus turbines.

The Gorlov turbine blades are of helical structure [29], [30] while Savonious turbines consist of straight or skewed blades which are of drag type devices [31].

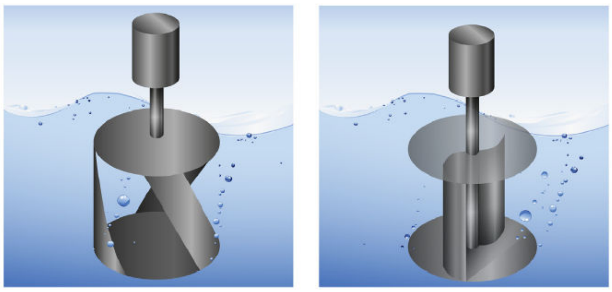
Hydrokinetic turbines may also be classified based on their lift/drag properties, orientation to up/down flow, and fixed/variable (active/passive) blade pitching mechanisms. Different types of rotors may also be hybridized (such as Darrieus–Savonious hybrid) in order to achieve certain performance features [20].



(a) In-plane axis (b) Squirrel cage Darrieus



(c) H-Darrieus (d) Darrieus



(e) Gorlov (f) Savonius

Fig. 6 Vertical axis turbines

B. Operation Principle

The hydraulic operation of a water turbine can be characterized by the following overall quantities: the rotor torque (Q), the rotor drag (D), the rotor angular velocity (w) and the power output P = w.Q as shown in Figs. 7, 8. By dimensional analysis, these quantities can be made dimensionless as follows:

$$\lambda = wR/V0 \text{(tip speed ratio)} \quad (1)$$

Tip speed ratio (TSR) is the ratio between the rotational speed of the tip of blade and the actual velocity of water.

$$C_Q = Q/\ (1/2\rho V_0^2.R.S_{ref}) \text{ (torque coefficient)} \quad (2)$$

$$C_P = P/(1/2\rho V_0^3 S_{ref}) \text{(power coefficient or efficiency)} \quad (3)$$

$$C_D = D/(1/2\rho V_0^2 S_{ref}) \text{(rotor-drag coefficient)} \quad (4)$$

R is the maximum radius of the rotor, U_{inf} is the incident current velocity, ρ is the water specific weight, S_{ref}, is the cross section (S_{ref}=ΠR^2 for horizontal axis and S_{ref}=2RH for vertical axis). The solidity is defined as σ= NC/R with N as the number of blades and C is the chord length [32], [33].

The considerable maximum power coefficient is 0.59 using well-known Betz law [34], [35] but a small-scale river turbine will certainly have its own losses which will reduce the power coefficient to around 0.25 [16].

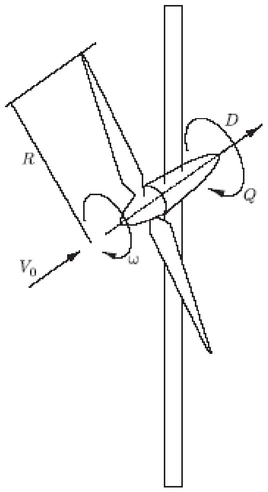


Fig. 7 Characterize operation of Horizontal axis turbines

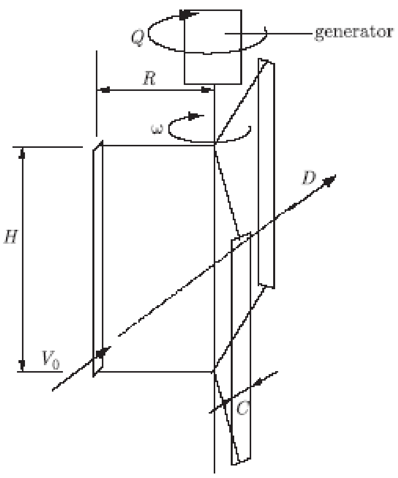


Fig. 8 Characterize operation of vertical axis turbines

IV. Performance

The conversion of kinetic energy of water is done by vertical and horizontal turbines where the turbine blades would turn the generator and capture the energy of the water flow to produce electricity.

In order to quantify the performance of turbines, many researchers focus on increasing the output power of turbines. The power coefficient (Cp) shows that the hydrokinetic turbines can only harness a fraction of the total kinetic power thus; improvement on turbine system is required to reach a high value of performance coefficient (VPC).

The Performance coefficient C_p depends on the velocity of current and design of system. Increase of C_p which can be done in two ways [36]. One of them is by increasing the water current velocity by:

1) Installing the turbine system at places where the land slopes or water current velocity are relatively higher.
2) Increasing water flow speed by creating man-made channel, where the frictional resistance can be minimized.
3) Increasing water flow velocity at the inlet of turbine by using nozzle or duct [37]-[39].

Another method is increasing the performance coefficient of the system by improving the blade form, profile or include more information about new design or developing other turbine system as seen in [13], [14], [40]-[46].

V. Conclusion

Nowadays, growing population, electricity demand and pollution due to fossil fuels have encouraged people encourages to use renewable energy instead of fossil fuels. Hydropower is undeniably the first choice for renewable energy that can harness the kinetic energy of water by implementation of turbines. Improvement of turbines is compulsory increase their performance.

Today, many researchers attempt to offer new concept, new design or new device to enhance performance coefficient.

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