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Cost Assessment of Hydrokinetic Power Generation

Anurag Kumar[1*] Abhishek pandey[2]

[1*]*Mechanical Engineering, Krishna Engineering College, Ghaziabad India*

[2]*Mechanical Engineering, ABES Engineering College, Ghaziabad India*

ABSTRACT

Small hydro power is one of the recently growing water energy source. Further, Hydro kinetic resource in flowing stream such as river, ocean current comes under the small hydro energy generation and it is recently developed turbine technology which taps kinetic energy from flowing water streams. This technology is not mature yet to generate electricity economically. Various attempts have been made to design and innovate the hydrokinetic turbine. Some of the turbine is under installation process and experimental phase. However, very few studies have been made to assess the cost of hydrokinetic power generation. This paper work presents cost assessment of hydrokinetic turbine based small hydro power generation. Three type of hydrokinetic turbine are considered to investigate cost of power generation and it is also compared the cost of generation for each turbine. A number of newly identified low head hydropower sites of Maharashtra state are analysed and cost/kWh has been calculated.

Keywords: Small Hydro, Hydrokinetic, Renewable Energy, Generation Cost, Turbine.

I INTRODUCTION

Small hydro power has very vast potential in rivers and it can be harnessed by hydrokinetic devices which are very recently developed turbine technology. Hydrokinetic turbines extract the kinetic energy which is available in flowing water. Hydrokinetic turbine converts the kinetic energy of water to the electrical energy through the alternator which is combined with it on the shaft of the turbine. A key advantage of this technology that turbine is deployed on flowing water with least civil works. Hydrokinetic turbine is works on the same principle of wind turbine and it has maximum power conversion limit lie within the Bet'z limit [1]. Hydrokinetic power from the flowing water is function of water density (ρ), flow velocity (v), swept area (A). And it is termed as:

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

Where, Cp is the power coefficient for turbine. It has the maximum Bet'z limit 0.59.

Kinetic power is mainly depended upon the flow velocity and the swept area. There are many attempt has been made to mature and improve this technology. Researchers have been identified various hydrokinetic turbine

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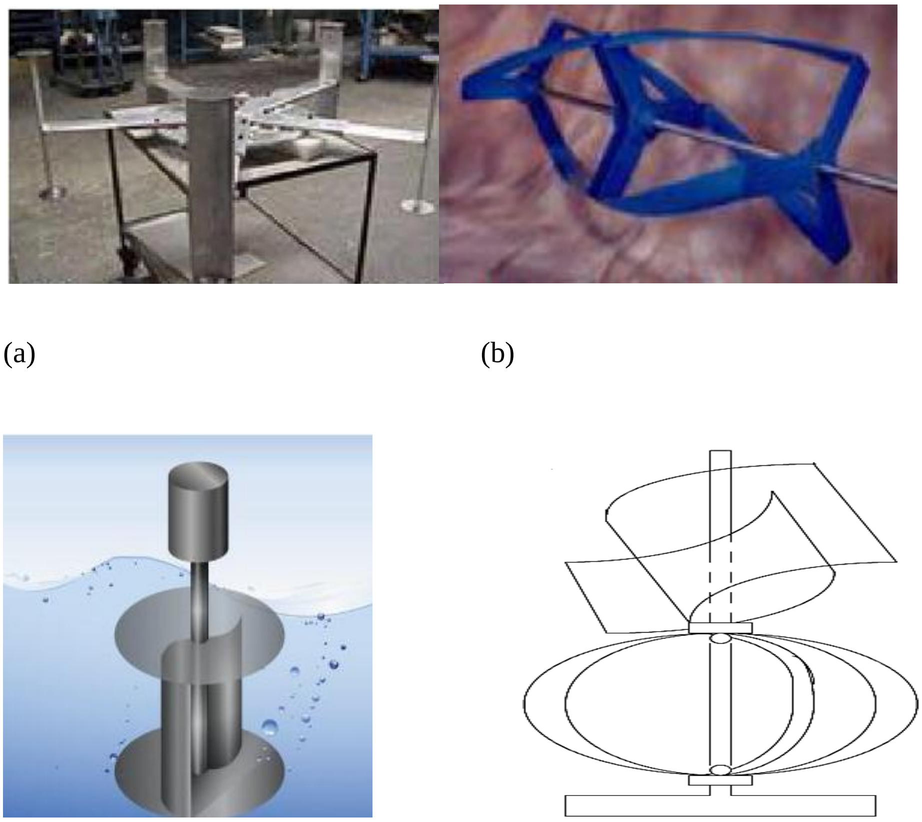
design such as Darrieus [2], Savonius [3], Gorlov Helical [4], Hybrid Darrieus – Savonius [5] etc. and shown in Fig.1.



(a) (b)

(c) (d)

Figure.1 Typical hydrokinetic turbines (a) Darrieus (b) Gorlov helical (c) Savonius (d) Hybrid Rotor Darrieus-Savonius

Recently various studies have been made to improve the coefficient of power such as blockage and free surface effects [6], ducted turbine installation [7], variable pitch of turbines [8] etc. It has been found that the helical blades Darrieus turbine can extract power efficiently than straight blade Darrieus turbine [9]. Many researchers have been studied the hydrokinetic turbine technically and found various essential parameters such as Tip Speed Ratio (TSR), blade pitch angle, attack angle, hydrofoil profile of the blade, Reynolds number, Power and torque coefficient are very important to design the turbine efficiently [10-17]. It has been found that the augmentation of the hydrokinetic turbine improves the rated power generation of the turbine and it facilitate better conversion of pressure energy into kinetic energy which results in increase of turbine efficiency[18]. There are substantial work has been done to develop the efficient hydrokinetic turbine but still this technology is not mature yet.it has been identified by Kumar, A. et.al [19] the hydrokinetic turbine cost and cost of power generation is very essential to take with innovation and design consideration. It is important to say that economic studies for hydrokinetic power generation is required to adopt this technology and analysis of Levelized cost of generation should be transparent and adequate[20].Today, the cost of power generation through hydrokinetic turbine technology is an arising question. In present research work, various rivers of Maharashtra state has been considered, and cost of power generation using Darrieus, Savonius and Gorlov Helical hydrokinetic turbine are calculated. Cost of hydrokinetic turbine is considered from past research work which was based on techno-economic viability of hydro kinetic turbine.

Small hydro Hydrokinetic River Projects:

Hydrokinetic river projects are those in which hydrokinetic turbines are installed in flow of water. Hydrokinetic turbines can be moored or anchored on river bed and can be floated over the flow. Moored or anchored hydrokinetic project would be two types fixed or partial fixed. Fixed anchored hydrokinetic turbines are installed on concrete base structure in the river or marine. However, the partial fixed turbine are anchored by steel cables attached to it and river banks.

Floating hydrokinetic turbine are floats on pontoon or light weight floating plate form on which the hydrokinetic turbine and alternator are installed. Fig.2 shows the following two types of hydrokinetic foundation installation [21].

(a) Fixed hydrokinetic turbine (b) Floating Hydrokinetic turbine Figure.2 hydrokinetic projects [21]

It can be seen from the Fig.2 that hydrokinetic turbine can be installed in running flow. These turbine can be installed single one and can be in cascade arrangement to increase the power generation [21].

Components of hydrokinetic power projects:

The basic components of hydrokinetic projects can be broadly classified as Electro-mechanical works and foundation/ anchoring works. However, some times less civil works also required and it is depend upon river sites.

Electromechanical components consist of the following major equipment.

(1) Hydrokinetic turbine
(2) Gear box
(3) Alternator
(4) Electrical transmission cables

Civil works and foundation have following components

(1) Pontoon boat
(2) Mooring structure
(3) Anchoring cables
(4) Foundation structure concrete

Requirements of these components depend upon the site conditions of the river such as River depth, flow, bed soil condition channel structure etc.

Mathematical modelling used to assessment of cost of power generation:

A mathematical modelling of cost estimation has been used which was formulated by Kumar. A [19]. A different hydro power sites, has been considered from Maharashtra state which are in ultra-low head range (0.5-3) m. Three types of hydrokinetic turbine have been considered which are included Straight Blade Darrieus, Savonius and Gorlov helical turbine.

A mathematical regression model [19] has been used to find out the cost of generation using the selected turbine. The following mathematical equation has been used to find out the cost/kW of turbine and alternator.

Table.1 Summary of cost correlation of ultra-low and zero head turbine [19].

Turbine Type	**Equation for cost per/kW**	**a**	**b**	**c**	**R^2**
Darrieus	$272392.68 \times P^{-0.0641} \times V^{-0.0076}$	272392.68	-0.0641	-0.0076	0.99
Savonius	$249197.24 \times P^{-0.0748} \times V^{-0.0848}$	249197.24	- 0.748	-0.848	0.50
Gorlov helical	$257815.63 \times P^{-0.0941} \times V^{-0.1183}$	257815.63	-0.0941	-0.1183	0.647

Cost data of generator has been analysed through the regression model and cost equation of generator can be given as:

C (In `) = (-0.7888 $P^2$ + 163.66 P + 1440.1) *62 (`/kW) (2)

Where, P is rated capacity of generator. This cost relation has been used to estimates the cost of turbine system. To estimate, costs of other components, it has been assumed from the past experience of hydropower projects such as cost of installation, interest during projects construction, depreciation, foundation or anchoring system. The table 2 has shown the contribution of cost of different components.

Table 2. Assumption used for turbine costing

Parameters	**Value**
Mooring structure	10 % (Ct +Ca)
Interest during construction	1-2 % (Ct +Ca)
Depreciation	0.03 % (Ct +Ca)
Electro-mechanical Auxiliaries	1 % (Ct +Ca)
Installation cost	20 % of (Ct +Ca+ Cm)

Analysis of cost of hydrokinetic energy for ultra-low head (0.5-3m) hydropower sites:

A typical design of Darrieus, Savonius, and Gorlov helical turbine and installation layout has been considered to analyse the cost of generation of hydrokinetic turbine. Fig.2 has been shown a typical layout of the hydro kinetic turbine such as Darrieus. As it is discussed earlier that anchorage of hydrokinetic turbine is important and generally, Turbines with solid mooring structure require the generator unit to be placed near the river or seabed. Horizontal axis rotors with a buoyant mooring mechanism may allow a non-submerged generator to be placed closer to the water surface [22]. As we can see from the Fig.2 there are mainly four components which are important for installation of hydrokinetic turbine. Gear box some time may not be required where the low rpm permanent magnet generator has been used. All the three turbines have been analysed under the velocity range of 1- 5 m/s and available frontal area of the turbine is 0.42 to 2.42 m2. For hydrokinetic turbine installation, the ultra low head range (0.5 -3.0 m) hydropower sites has been considered. A total 39 hydropower sites has been identified for cost of power generation.

Using the flow data of these sites, theroritical power has been calculated which is given in table 3. Table 3 shows the maximum (betz's limit) available power at these sites which can be extracted from Darrieus, Savonius and gorlov helical turbines. The total cost of the turbine has been calculated using the cost correlation given in table 1 and Assumption given in table 2. Generator cost has been calculated using equation 2.

The cost of genariation has been calacualted as given below. Cost of generation(INR/kWh) = Mooring structure + Intrest during or manufacturing cost + depriciation + Istallationcost+electromechanical Auxilaries)/(TotalkWh*8760)

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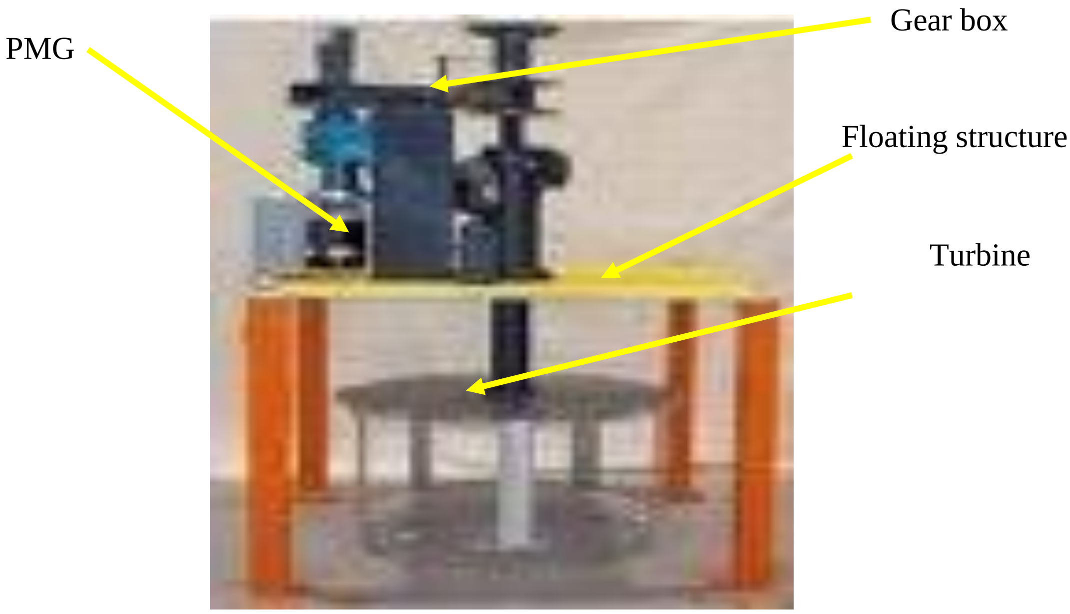

Figure 2 Typical layout of hydrokinetic turbine mainly Darrieus, Savonius and Gorlov Helical.[2]

A similar analysis and data has been calculated for Savonius and Gorlov Helical turbine. Aregression analysis has been studied to identify the correlation for cost generation estimation for forecasting at different sites. The Fig.3 shows the plot of cost of generation (`/kWh) vs velocity of flow (m/s).

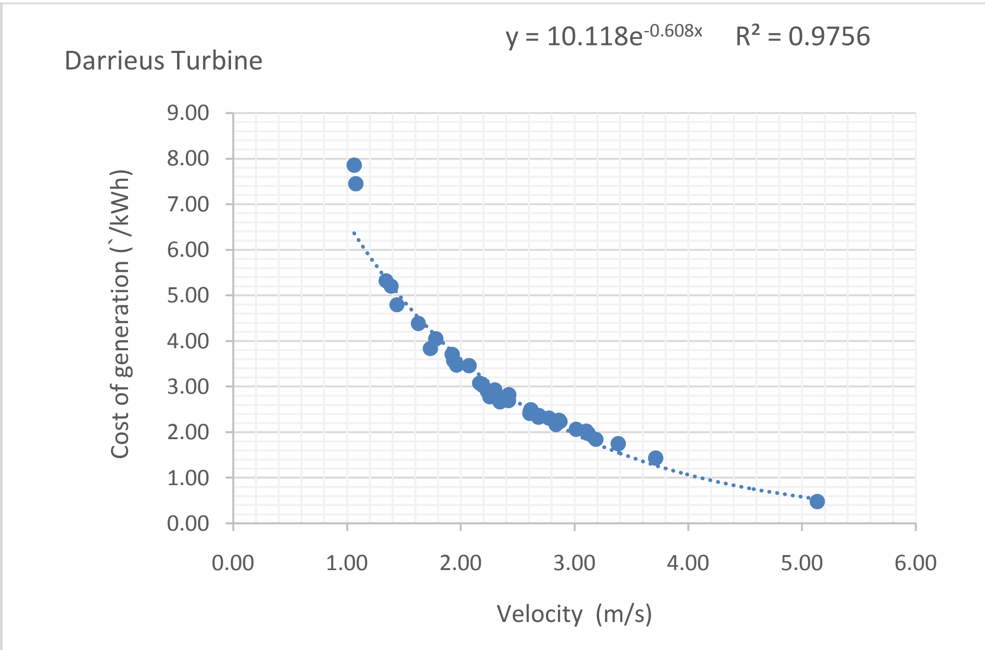

Figure. 3. Regression curve of Darrieus turbine cost of generation vs velocity

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As it can be observed that the cost of generation depends velocity of flow and has correlation constant R = 0.9756. It has been seen from Fig 3 cost of generation decreases as flow velocity increases at the same size of turbine used.an similar study of the regression analysis has been carried out for Savonius and Gorlov helical turbine. Cost of generation and velocity plots for Savonius and Gorlov Turbine are shown in Fig. 4 and Fig. 5.

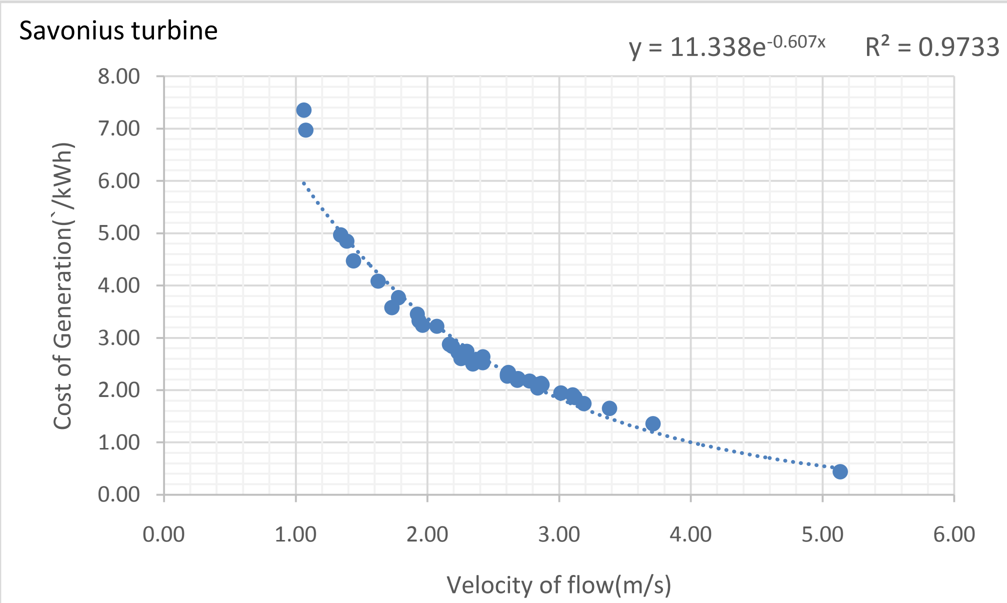

Figure. 4. Regression curve of Savonius turbine cost of generation vs velocity

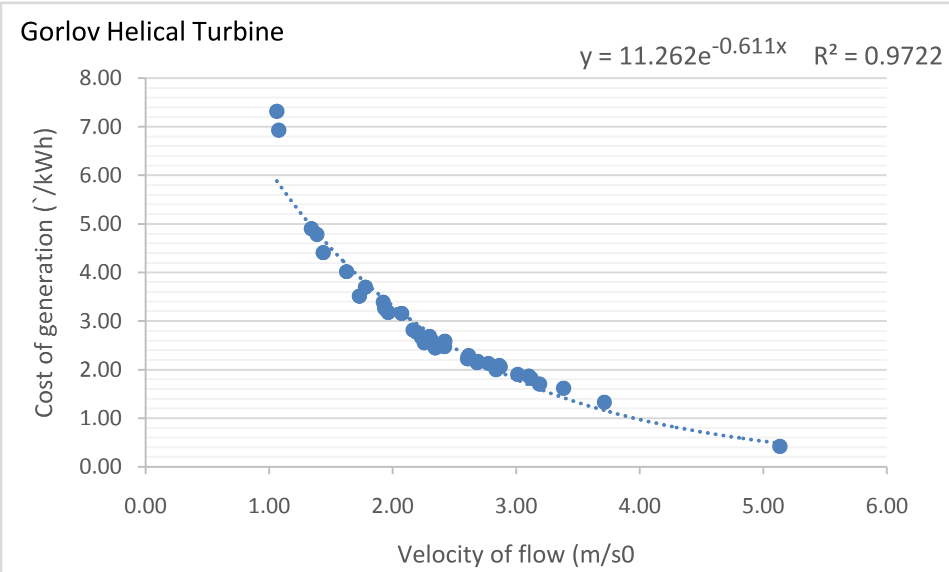

Figure. 5. Regression curve of Gorlov Helical turbine cost of generation vs velocity

There is similar trends has been found for Savonius and Gorlov helical turbine and regression coefficients for both turbine plots are near 1.0. From the analysis of Darrieus turbine maximum velocity of flow 5.14 m/s generates low cost power

Similarly for the Savonius turbine has generation cost 0.43 `/kWh and 7.35 `/kWh for same minimum and maximum velocity of flow. Gorlov helical turbine has minimum cost of generation that is 0.42 `/kWh at max available flow velocity 5.14 m/s. and has maximum cost of generation 7.32 `/kWh at minimum flow velocity 1.06 m/s.

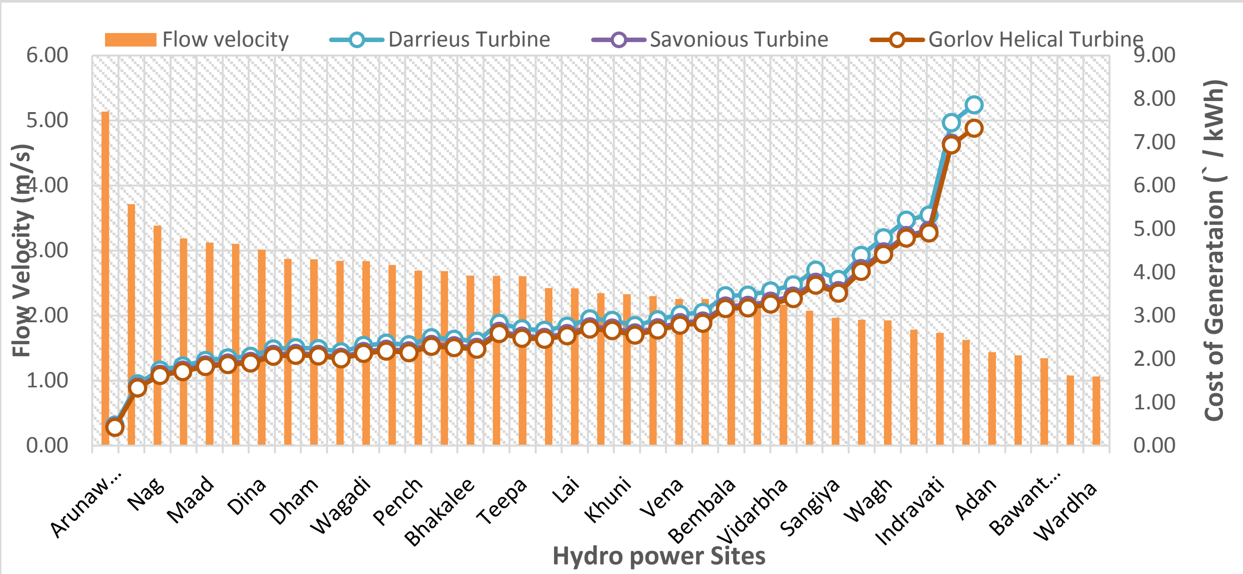

Figure. 6 Cost of generation of hydropower sites of Darrieus, Savonius and Gorlov helical turbine with respected to flow velocity.

Combine trends of cost of generation for different hydropower sites have been plotted in Fig 6. It gives the complete information of the sites which has maximum and minimum cost of generation using Darrieus, Savonius and Gorlov helical turbine. As it has been found that Arunavati sites has highest flow velocity 5.14 m/s in among sites. Therefore the cost of generation for all three turbine has lowest. However, the Gorlov helical turbine is best turbine for the cost of generation point of view. Wardha Hydro power site has lowest flow velocity and highest cost of generation.

As it can be observed cost of generation from the Darrieus type turbine is highest for all hydro power sites than the other two hydrokinetic turbines Savonius and Gorlov Helical. As the power coefficient of the Gorlov helical turbine is higher than the Darrieus and Savonius turbine and the cost correlations in table 1 has been used which are identified by using power coefficient of the turbines. However, in this work the maximum Bet'z limit hasbeen considered to carry out the maximum power available and the cost of generation at that particular power.

II CONCLUSIONS

To carryout cost of power generation is important to analyse the pre-feasibility of the power project. In this paper, the various sites of hydropower from Maharashtra State have been considered to carry out the cost of generation at different site conditions. Identified correlations and assumption have been used to calculate different types of cost of power projects and cost of generation also. Based on the above analysis following conclusion are find out.

(1) Flow velocity is a critical parameter on which the cost of generation depends.

(2) It has been found that the Gorlov Helical turbine is best option to install at low head hydropower site.

(3) It has been observed that cost of generation decreases as decrease in velocity of flow.

(4) Further studies have been suggested to carryout detailed feasibility study of these turbine in ultra-low head flow stream.

REFERENCES

[1] Guney, M.S. and Kaygusuz, K., “Hydrokinetic energy conversion systems: A technology status review”, Renewable and Sustainable Energy Reviews, 14(9):2996–3004, 2010. http://dx.doi.org/10.1016/j.rser.2010.06.016

[2] Khan, M. J., M. T. Iqbal, and J. E. Quaicoe. "Design considerations of a straight bladed Darrieus rotor for river current turbines." Industrial Electronics, 2006 IEEE International Symposium on. Vol. 3.IEEE, 2006.

[3] Nakajima, Miyoshi, ShouichiroIio, and Toshihiko Ikeda. "Performance of Savonius rotor for environmentally friendly hydraulic turbine." Journal of Fluid Science and Technology 3.3 (2008): 420-429.

[4] Gorlov, A. M. "The helical turbine: A new idea for low-head hydro." Hydro Review 14.5 (1995).

[5] Gupta, R., R. Das, and K. K. Sharma. "Experimental study of a Savonius-Darrieus wind machine."Proceedings of the International Conference on Renewable Energy for Developing Countries.Washington, DC., USA. 2006.

[6] Birjandi, Amir Hossein, et al. "Power measurement of hydrokinetic turbines with free-surface and blockage effect." Ocean Engineering 69 (2013): 9-17.

[7] Malipeddi, A. R., and D. Chatterjee. "Influence of duct geometry on the performance of Darrieus hydro turbine." Renewable Energy 43 (2012): 292-300.

[8] Paillard, B., FrédéricHauville, and Jacques Andre Astolfi. "Simulating variable pitch cross flow water turbines: A coupled unsteady ONERA-EDLIN model and stream tube model." Renewable Energy 52 (2013): 209-217.

[9] Kirke, B. K. "Tests on ducted and bare helical and straight blade Darrieus hydrokinetic turbines." Renewable Energy 36.11 (2011): 3013-3022.

[10] Anyi, M. and Kirke, B., “Hydrokinetic turbine blades: Design and local construction techniques for remote communities”, Energy for Sustainable Development 15(3):223–230, 2011.

[11] Arslan, A., Khalid, R., Hassan, J., and Manarvi, I. A., “Design and Manufacture of a Micro Zero Head Turbine for Power Generation”, International Journal of Multidisciplinary Sciences and Engineering, 2(7): 35-38, 2011.

[12] Bayandor, J., Abanteriba, S. and Bates, I.,"Principles of a new zero head hydro-propulsive system." In Proceedings of the 34th joint power generation conference, 2: 615-20, 1999.

[13] Filho, G. L. T., Dsouza, J., Rossi, C. A. B., Barros, R. M. and F das G Braga da Silva, “Poraque” hydrokinetic turbine, IOP Conf. Series: Earth and Environmental Science 12: (p.13) 012094, 2010.

[14] Kinsey, T. and Dumas, G., “Optimal Tandem Configuration for Oscillating-Foils Hydrokinetic Turbine”, Journal of Fluids Engineering, 134(3): 031103, 2012.

[15] Zhen, H. and Xiaoping, D., “Reliability Analysis for Hydrokinetic Turbine Blades”, Renewable Energy 48:251-262, Dec, 2012.

[16] Tavani, H.M., “River's Meander Energy Conservation as a Renewable Energy Recourse, a Mathematical and Technology Status Review”, Advanced Materials Research, 433: 1132-1136, 2012.

[17] Morcos, S. M. and Mikhail, S., “Model Tests of Schneider Turbine for Low-Head Hydropower Plant”, Journal of Energy Engineering, 112(3):185-198, Dec, 1986. ASCE.

[18] Khan, M. J., Iqbal, M.T. and Quaicoe, J. E., “A Technology Review and Simulation Based Performance Analysis of River Current Turbine Systems”, IEEE, pp.2288 – 2293, 2006.

[19] Kumar, A., “Techno-economic analysis of ultralow and zero head turbine.”(Thesis) AHEC, Indian institute of technology Roorkee, India, 2014.

[20] LaBonte, Alison, et al. "Standardized cost and performance reporting for marine and hydrokinetic technologies." Proceedings of the 1st Marine Energy Technology Symposium (METS13), Washington, DC, USA. 2013.

[21] Filho, GL Tiago, et al. "“Poraque” hydrokinetic turbine."

[22] Khan, M. J., et al. "Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review." Applied Energy 86.10 (2009): 1823-1835.

[23] Behrouzi, Fatemeh, et al. "An Innovative Vertical Axis Current Turbine Design for Low Current Speed." JurnalTeknologi 66.2 (2014).