SELECTION OF HYDROKINETIC TURBINES

A DISSERTATION

Submitted in partial fulfillment of
Requirement for the award of the degree

of

MASTER OF TECHNOLOGY
in

ALTERNATE HYDRO ENERGY SYSTEMS

By

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CANDIDATE'S DECLARATION

I hereby declare that the work which is presented in the this evaluation of dissertation, entitled "**SELECTION OF HYDROKINETIC TURBINES"** submitted in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **Alternate Hydro Energy Systems** in **Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee**, is an authentic record of my own work carried out during the period from July 2018 to May 2019 under the supervision and guidance of **Prof. S. K. Singal, and Prof. R.P. Saini, Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, (India).**

I also declare that I have not submitted the matter embodied in this report for award of any other degree.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge**.**

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ABSTRACT

Water current turbine or hydrokinetic turbines are used to generate electricity directly from the flowing water in a river or a stream and practically no head is needed to produce the small scale power. This technology has not been conventionally adopted so far and can be future renewable energy source for developing countries. Most of the hydrokinetic potential of river currents has not been explored till now, due to less awareness and in-efficient technologies of hydrokinetic turbines compared to conventional turbine.

Under the present dissertation work, an attempt has been made for selection of hydrokinetic turbine under the different condition. Based on the literature survey, steps are evolved for selection of hydrokinetic turbine, it is necessary to obtain the Coefficient of Performance and efficiency based on the working parameters techniques such as tip speed ratio, aspect ratio, overlap ratio and field parameters techniques such as Reynolds number, Froude number, free flow velocity, water density, flow variability, velocity and turbulence and effect of depth variability in river, manmade canal, irrigation canal, or ocean. Further by identifying the sites and analyzing the hydrokinetic potential for the water resources and characteristic of different sites have been studied thoroughly. The various parameters are studied which are required to select the turbine under different field condition parameters like velocity of stream and depth of flow. After studying published works of various authors and collecting data from literature, a nomogram is prepared for diameter v/s speed of turbine considering the velocity of flow.

It has been observed that for low speed (rpm) and minimum tip speed ratio, Savonious turbine is suitable. While for large variation of speed, Horizontal axis turbine is suitable with variation of diameter from 280 mm to 3000mm. It is also found that installation parameters play a critical role to enhance the performance of hydrokinetic turbine. It is necessary to prepare suitable selection procedure of hydrokinetic turbine for a site under different working conditions.

CONTENTS

LIST OF FIGURE

LIST OF TABLES

NOMENCLATURE

S.NO.	SYMBOLS	DESCRIPTION	UNITS
1.	υ	Kinematic viscosity	m^2/s
2.	P	Density of the water	kg/m^3
3.	V	Free stream velocity	m/s
4.	A	Frontal area of turbine	m^2
5.	D	Diameter of the rotor	m
6.	R	Radius of turbine	m
7.	H	Height of turbine rotor	m
8.	C	Chord length of blade	m
9.	N	Number of blades	-----
10.	G	Gravitational acceleration	m/s^2
11.	P_{in}	Kinetic Power	W
12.	P_{out}	Rotor Power	W
13.	H	Efficiency	-----
14.	λ	Tip speed ratio(TSR)	-----
15.	Cp	Coefficient of performance	-----
16.	C_T	Torque Coefficient	-----
17.	C_L	Lift Coefficient	-----
18.	C_D	Drag Coefficient	-----
19.	σ	Solidity	-----
20.	T	Torque on the shaft	N-m
21.	ω	Angular velocity of the turbine	rad/s
22.	N	Rotational speed of shaft	RPM
23.	α	Angle of attack	Degrees
24.	AR	Aspect Ratio	----

25.	Re	Reynolds Number	----
26.	D	Depth of water in the channel	m
27.	n_s	Number of revolution per second measured by water velocity logger meter	Rps

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The hydro kinetic turbine is a turbine with the kinetic energy of flowing waters to generate an electrical power. It is known as a so-called "in-stream" turbine because it is driven by kinetic energy instead of potential energy. Hydrokinetic turbines convert the kinetic energy into mechanical energy, just like wind turbines transform the wind's energy. This energy is further converted into electricity. In this head differential and/or no dams are necessary for the operation of this device; the course of a river remains in its natural state and no high investments for infrastructure are required. Because the amount of kinetic energy varies from river to river, a greater amount of energy is generated with a higher velocity of stream flow.

These turbines for canals and rivers allow for a base load supply, providing a complete renewable energy for the best effective. cost-benefit possible. This technology is standardized and easily scalable. Although qualifying as "green" these products are positioned as the best alternative for decentralized electrification along rivers. Increasing energy demand, harmful environmentaleffects of conventional energy productio technologies, increasing cost and running out reserves of fossil fuels, climate change, health problems and social problems have led scientists and engineers to find alternative non-consuming, harmless, cheaper and sustainable energy production methods. Renewable energy technologies give many environmental benefits over conventional energy sources.

1.2 NON RENEWABLE ENERGY SOURCES

Conventional energy sources based on coal, oil, and natural gas have verified to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health. In addition, subject to the impacts of oligopoly in manufacturing and distribution, they tend to be cyclical in nature. These traditional fossil-fuel energy sources face growing pressure on a variety of environmental fronts, with the Kyoto Protocol greenhouse gas (GHG) reduction objectives being perhaps the most severe challenge facing the future use of coal. It is now clear that any effort to maintain atmospheric levels of CO_2 below even 550 ppm cannot be based fundamentally on an oil and coal-powered global economy.

1.3 RENEWABLE ENERGY TECHNOLOGY

Stream flow is an essential concept of water power. There are two approaches of extracting energy from water flow. The conventional method is to make a dam for constitution of a stati head. The another method is extracting energy from different water currents such as tidal, ocean, river and irrigation canals. Kinetic energy and potential of rivers are based on the distribution of water velocities rather than stream flows, indicates higher values. A river current energy conversion system can be described as an energy converter which harnesses the kinetic energy of river streams.

1.4 RENEWABLE ENERGY SOURCE

Renewable energy resources (solar, wind, hydropower, geothermal and biomass) are most comprehensive solution for environmental and energy scenarios problems. For future energy consumption renewable energy is the new emerging resources to take part in energy demand role. The use of renewable energy sources (RES) plays a vital role to reduce both (CO_2) emissions and fossil fuel dependency Due to environmental friendly, cost-effective and technical benefits, SHP plants have become promising alternative than other energy resources [2].

1.4.1 Biomass Energy

Biomass is the term used for all organic material originating from plants (including algae), trees and crops and is essentially the collection and storage of the sun's energy through photosynthesis. Therefore it can play an important role to meet the future energy mix in many countries. India is an agricultural country, so biomass is available in large quantity in the form of husk, straw, jute, cotton, shells of coconuts wild bushes, etc.

The total potential of biomass power generation in India is mainly Uttar Pradesh, Punjab, Karnataka, Bihar, Gujarat, Tamil Nadu; And Andhra Pradesh states of India have very large biomass/bioenergy Potential. Raw biomass faces many difficulties to compete with fossil fuels in many applications because of its physical characteristics. However, pretreatment of solid biomass can improve its competitiveness. Biomass energy, or bioenergy, is the conversion of biomass into useful forms of energy such as heat, electricity.

1.4.2 Wind Energy

It has considerable potential as a global clean energy source, being both widely available, though diffuse, and producing no pollution during power generation. The electricity from wind energy can be generated in rural and remote areas. It is a clean alternative energy source as compared to conventional fuel. In order to tap the potential of wind energy sources, the scientific wind mapping has been done extensively.

1.4.3 Solar Energy

There are two fundamental categories of techniques that turn sunlight into useful forms of energy, apart from biomass-based systems that use photosynthesis from plants as an intermediate step to do this in a wider sense. First, photovoltaic (PV) solar modules directly transform sunlight into electricity. Second, solar thermal power systems use concentrated solar radiation to generate steam, which is then used to transform electricity generating a turbine. Solar PV modules are unmoving solid-state semiconductor equipment that convert sunlight into direct-current electricity.

1.4.4 Geothermal Energy

Geothermal energy is simply the thermal energy inside the earth. Due to various processes inside earth, especially like rocks heating up or volcanic activity underground produces areas with large temperature difference. These temperature differences can be exploited to produce huge amount of energy. Heat is extracted from geothermal reservoirs using wells or other means.

1.4.5 Ocean Energy

This type of energy derives from potential, kinetic, thermal and chemical energy of sea water which can be transfer to provide electricity thermal energy or portable water. A wide range of technology are possible such as barrage for tidal range submarine turbines for tidal and ocean currents, heat exchanger for ocean thermal energy conversion and a variety of device to harness the energy of waves and salinity gradients [3].

1.4.6 Hydro Power

Hydropower is a significant source of electricity worldwide and will likely continue to grow especially in the developing countries. While large dams have become much riskier investment. There still remains much unexploited potential for small hydro projects around the world.

Hydropower is the world's largest and cheapest source of energy. It is one the most efficient way for the generation of electricity. India's energy use is the fifth highest in the world. India's energy consumption has been increasing at a relative fast rate due to population growth and economic development in the last six decades, India's energy use has increased 60 times from 16kwh (1947) to 957kwh (2014) per capita and capacity from 1.36 GW in 1947 to 282 GW in 2015. The total electricity generating capacity of India stands at 282 GW with 70% share from thermal, 16% from Hydro, 2% from nuclear and 12% from wind, solar, small hydro and other renewable energy sources.

The all India average energy shortage is 2.3%, whereas peaking shortage is 3.2%. About 35% of Indian households do not have access to electricity. Out of the 597464 villages in the country, About 16067 is yet to be electrified. The responsibility to develop the Small hydro power projects (SHP) which have the capacity up to 25MW has been given to Ministry of New and Renewable Energy (MNRE) The estimated potential in India for such plants is about 20,000MW. In hydro power, there is divided into two categories one is conventional and another is nonconventional systems.Hydraulic head and flow rate are utilized by both system are shown in Fig 1.1.

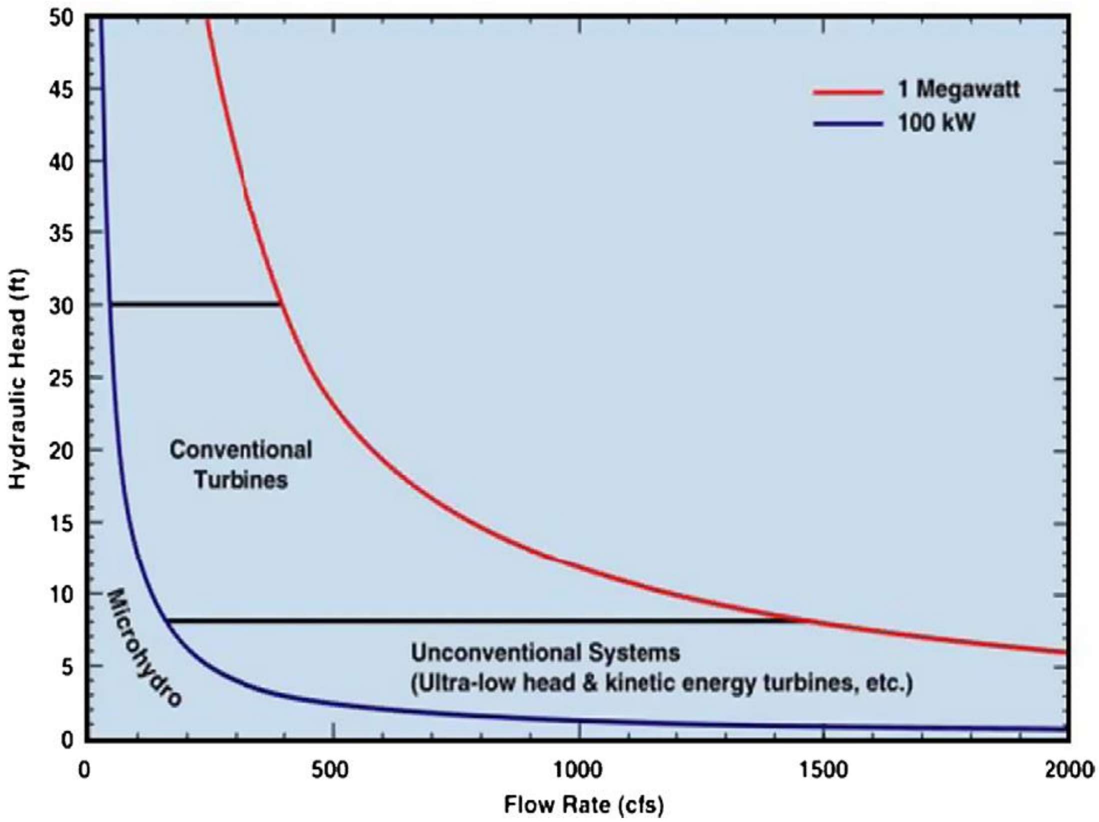

Fig 1.1 Conventional hydro versus hydrokinetic energy conversion scheme [7]

1.5 BENEFITS OF HYDRO POWER

As the prices of energy is increasing day by day, Hydro power can be a best solution to electrify the rural as well as urban area, furthermore hydro power do not consume water for the power generation. On the major advantage of this technology is that it is extremely robust and can last for 50 years or more with a little maintenance [4].Other advantages of hydro power are listed below.

i. Hydroelectric energy is non-polluting - no heat or noxious gases ar released.
ii. Hydroelectric energy has no fuel cost and with low operating and maintenance costs, it is essentially inflation proof.

iii. Hydroelectric energy technology is a proven technology that offers reliable and flexible operation.
iv. Hydroelectric stations have a long and many existing stations have been in operation for more than half a century and are still operating efficiently.
v. Hydropower station efficiencies of over 90% are achieved making it the most efficient of energy conversion technologies.
vi. Hydropower offers a means of responding within seconds to changes in load demand.
vii. Power Plants hardly discharge any form of solid, liquid or gaseous wastes into the ecosystem.
viii. Helps in sustainable usage of coal for power demands of the country.
ix. Multipurpose Hydro power projects- Help in flood moderation, irrigation, navigation and drinking water requirement.

1.6 LIMITATIONS OF HYDRO POWER

Even though there are many advantages associated with the Hydropower projects, the major drawbacks are listed follows.

i. Environmental consequences: Large hydro power projects have their own storage or poundage to collect water for yearlong water availability. Due to the water storage, the ground water level increases and due to this, vegetation in nearby areas due to increase in the water level. Water retention also lead to physical and chemical changes in the reservoir.
ii. Expensive: installation of hydropower projects is a costly affair. Dam construction, installation of turbine and powerhouse installation is very expensive. Because of the high installation cost. Many countries are not promoting hydropower projects.
iii. Effect on flora and fauna: Hydropower installation restrict the stream flow so it harms both the flora fauna in the reservoir area and downstream. Fishes are also restricted to move from upstream side to downstream side and vice-versa.
iv. Draughts ant Floods: In case severe hydrological conditions, hydropower projects some time fail to perform. High inflow causes silt deposition in the bed of the reservoir due to silt deposition, the net head of the projects decreases and this silt also damages the turbines and other mechanical parts.
v. Dam rupture reservoir based hydropower projects have high risk of the failure. Cracks in the dam wall due to earthquake, high inflow and rain fall can also harm the reservoir structure

1.7 HYDROKINETIC ENERGY

Hydrokinetic energy is the result of the natural movement of water within different systems. Rivers, tides, and waves all have the potential for harnessing movement to capture and generate hydrokinetic power. Hydrokinetic energy sources are classified in different ways, including offshore and inland generation. Offshore generation harnesses wave power and tides from coastal bodies of water such as oceans and seas. Inland generation is composed of run-of-river and in-stream tidal energies, both are secluded from the intensity of offshore areas. There is great potential for harnessing energy within inland areas because (a) it is easier to deploy equipment in these environments compared to those offshore, and (b) are more closely related to hydroelectricity currently being produced by other types of hydropower plants since all of these are in-land systems, i.e. impoundment dams, diversion method, etc [7].

The second reason is that system of nonrenewable hydropower is not sufficient to meet our increasing energy demand. Therefore in addition to conventional hydropower plant a new type of hydropower energy known as hydrokinetic power can be used to produce renewable electricity.

Hydrokinetic energy conversion systems are the electromechanical devices that convert kinetic energy of river streams, tidal currents, man-made water channels or waves into electricity without using a special head and impoundment. Hydrokinetic conversion system produces electricity by making the use of flowing water contained in river streams, tidal currents, or other man made water ways.

The hydro kinetic turbine is a turbine to produce an electrical power with the kinetic energy of flowing waters. Because it is powered by kinetic energy instead of potential energy

There are five main types of marine and hydrokinetic energy technologies;

i. Ocean wave
ii. Tidal stream
iii. River stream
iv. Ocean current and
v. Irrigation and other manmade canals.

1.8 ADVANTAGES OF HYDROKINETIC ENERGY

Hydrokinetic systems have minimal environmental impacts compare to dams. Large scale hydroelectric power plants have some unfavorable effects on the environment such as; people relocation, inundation of agricultural, historical and habitat areas, sedimentation of fertile lands, methane (CH_4) gas emission, altering the river regime, etc. Contrarily, the natural issue of the energy production site is not seriously affected by hydrokinetic systems. Some other advantages of hydrokinetic energy are listed below.

There are anumber of characteristics that make hydrokinetic energy system distinct from other hydropower system.

a) Do not require large civil works for implementation.
b) Operate in the water stream natural pathway and do not require a stream flow diversion.
c) Less noise and vibration issue than conventional turbine.
d) Do not require a hydraulic head difference.
e) Do not require a dam or barrage for operation.
f) Reduction in environ mental problems.
g) Hydro kinetic turbines used for harnessing the hydropower are fish friendly.
h) Low gestation period.
i) Negligible maintenance cost and low operation cost
j) Maximize the performance of hydropower plant by installation of hydrokinetic turbine at the down stream of the dam.

1.9 HYDRO KINETIC ENERGY CONVERTER SYSTEM

The working principle of hydrokinetic power is similar to that of wind energy and share similar design philosophies as shown in the Fig 1.2.The only properties that make it different from wind energy is the density of water which is 850 times greater than the density of air.

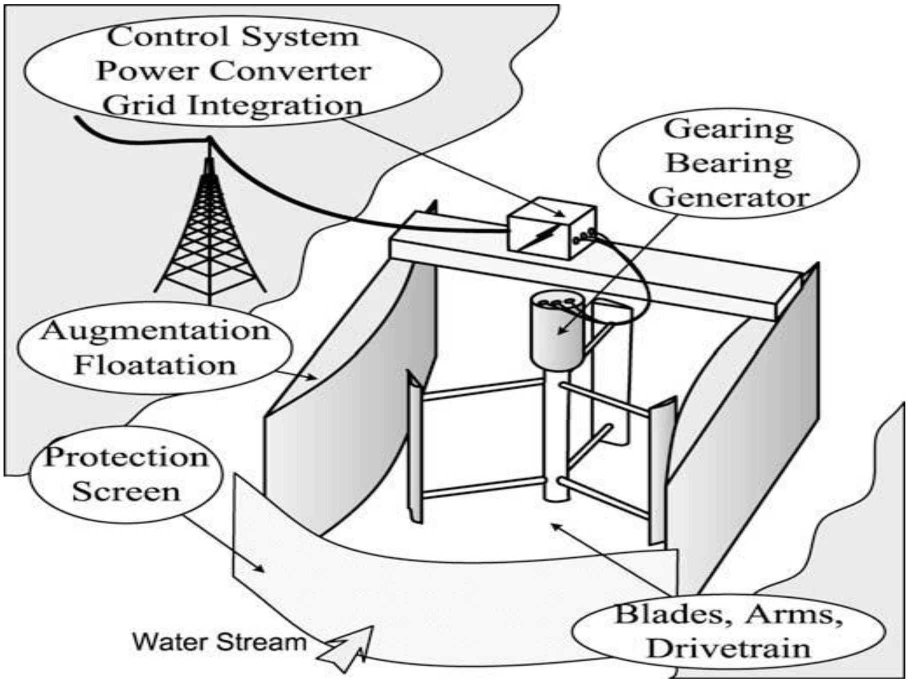

Fig 1.2 Outline of hydrokinetic energy converter system [7]

Water current turbines extract energy from the fluid by reducing flow velocity. There is a theoretical limit to the percentage of kinetic energy that can be removed from the flowing fluid to the kinetic energy maximum available in fluid. This limit is known as Betz limit. Betz limit is 59.3% for a single and open actuator disc. Power coefficient K is a measure of the fluid dynamic efficiency of the turbine and differs depending on manufacturer. It became a common practice to use this limit for estimating the maximum efficiency of such turbines. Performance coefficient takes different factors into account. Each turbine has a different maximum value of K which indicates the efficiency level of the turbine. It is important to remember that the Betz limit is valid open free flow turbine.

Theoretical power extraction from a hydrokinetic turbine can be determined from the density of a fluid, the velocity at which the fluid travels and cross sectional area at which the energy will be extracted.

$$P= \frac{1}{2} \rho A V^3 \qquad (1.1)$$

Where, P = Power in the flow, ρ= density of water (kg/m^3)

A= blade swept area (m^2), V= velocity of water (m/s.

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1.10 CLASSIFICATION OF HYDROKINETIC TURBINES

Hydrokinetic turbines, as discussed earlier uses the water mass flowing in rivers, canals and irrigation systems these turbines are totally than that of conventional types of turbine such as Pelton, Francis, and Kaplan.

Depending on the orientation of rotor axis with respect to the direction of water incoming water these turbines are mainly classified into two categories namely axial-flow turbines and cross-flow turbines as shown in Fig 1.3.

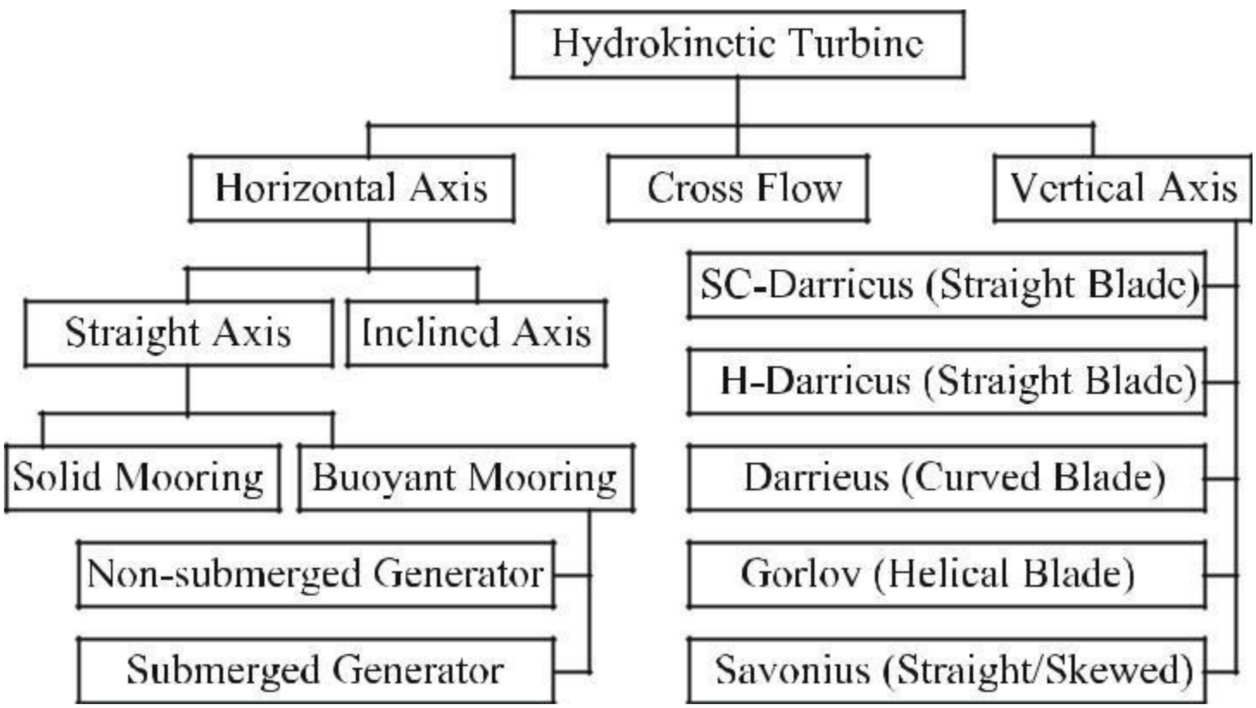

Fig 1.3: Classification of turbine rotors [7]

1.10.1 Axis flow Turbine

The turbines of the horizontal axis (alter-named as axial-flow) have axes parallel to the fluid flow and use propeller type rotor. Various axial turbine arrangeme nts are shown in Fig.1.4 for use in the hydro-enviroment.These can be fabricated using two blade, three blade, and multi blades. Those turbines which have their rotational axes parallel to the direction of incoming water are called horizontal axis turbine. These turbines are also known as axial flow turbines. These two names are used interchangeably in the literature. These types of turbine employ propeller type rotors. Inclined axis turbines have mostly been studied for small river energy converters. Horizontal axis turbines are common in tidal energy converter and are very similar to modern day wind turbines from concept and design point of view. Turbines with solid mooring structures require the generator unit to be placed near the riverbed. Horizontal axis rotors with a buoyant mooring mechanism may allow a non-submerged generator to be placed closer to the water surface.

When these axial flow turbines are operated in the same water flowing conditions then these may reach higher efficiency compare to cross flow turbines..

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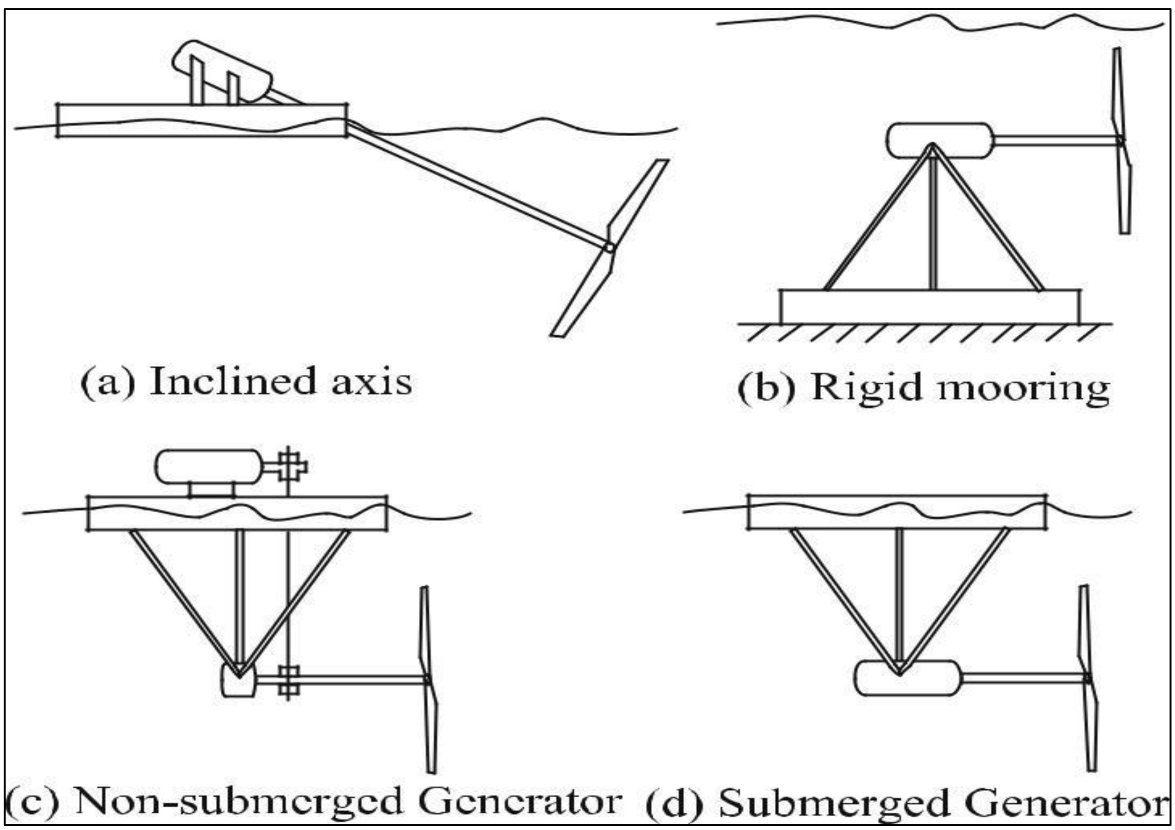

Fig. 1.4: Horizontal axis turbines [7]

1.10.2 Vertical Axis Turbine

Those turbines which has rotational axis of rotor is vertical to the water surface and also orthogonal to the incoming water stream are called vertical axis turbines. These turbines employ lift or drag type blades.Various arrangements under the vertical axis turbine category are given in Fig 1.5.

In the vertical axis domain, Darrieus turbines are the most prominent options. Although use of H-Darrieus or Squirrel-cage Darrieus (straight bladed) turbine is very common, examples of Darrieus turbine (curved or parabolic blades) being used in hydro applications is non-existent. The Gorlov turbine is another member of the vertical axis family, where the blades areof helical structure. Savonius turbines are drag type devices, which may consist of straight or skewed blades .Vertical axis turbines are more popular for river applications and horizontal axis turbines are mainly used for extraction of ocean energy.

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The large amount of material usag is another problem for such turbines . Darrieus turbines with cross flow arrangements may also fall under this category. Vertical axis turbines are more popular for river applications and horizontal axis turbines are mainly used for extraction of ocean energy.

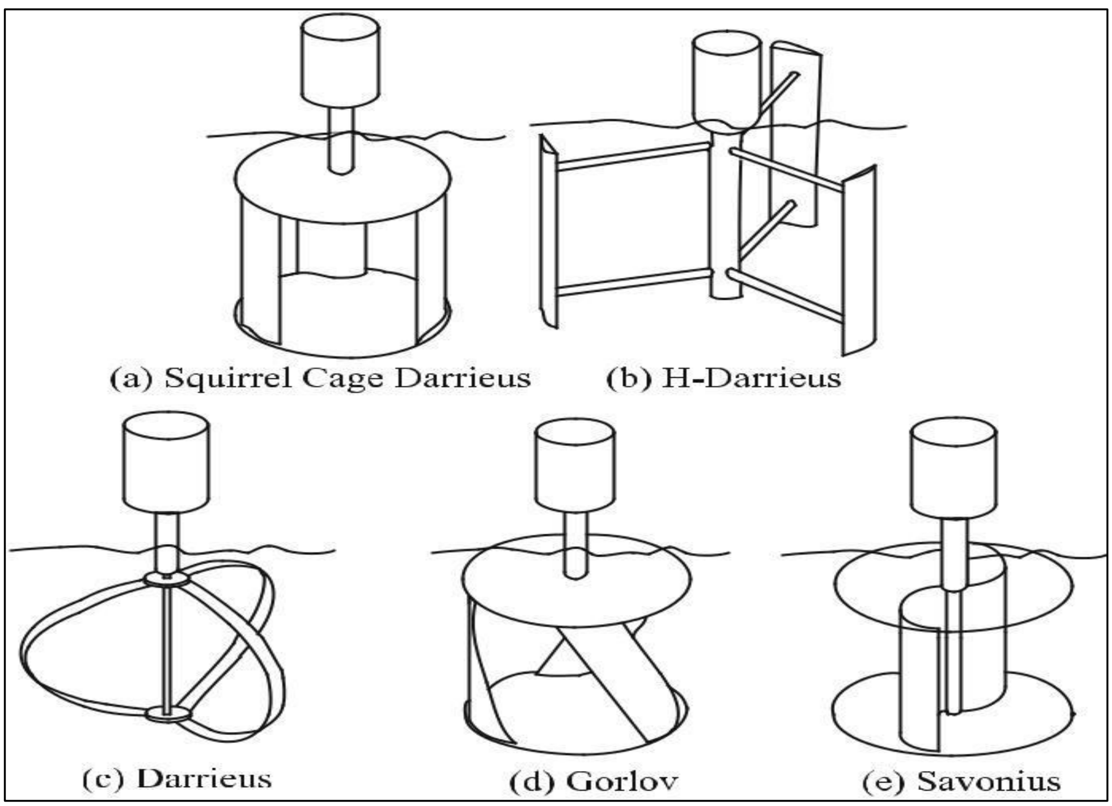

Fig 1.5 Vertical axis turbine [7]

1.11 COMPARISION BETWEEN HORIZONTAL AXIS AND VERTICAL AXIS HYDROKINETIC TURBINE

A classification of turbines based on th alignment of axis of rotor with respect to direction of water flow. Three classes could be formed (a) axial flow and (b) cross flow . Both types are discussed above but some specific parameters are compared in Table 1.1.

Table 1.1 The comparison between axial and cross flow hydrokinetic turbines [7]

S. No.	Attributes	Axial flow horizontal axis	Cross flow vertical axis turbine
1	Efficiency	Higher value	Lower value
2	Self-starting capability	Yes	Inability to self-start
3	Manufacturing Cost, maintenance cost& transportation cost	Higher	Lower
4	Shape of rotor	Disc type shape	Cylindrical type shape
5	Airfoil shape	Yes	Does not required
6	Blade size	Larger	Size of blade with smaller and simpler blade
7	Problems in river & canal stream	Clogged with debris found	Can deflect incoming debris

1.12 ENVIRONMENTAL IMPACTS

The effects on the habitats of benthic animals and plants like oysters, clams and sea grass. A big size array of hydrokinetic conversion system can create significant noises which can influences marine and river life. It seems that, underwater assembled and rotated devices causes some changes and impact on their environment discussed below.

- The devices can hinder the movement of aquatic animals.
- These impacts can be minimized by appropriate site selection project design and proper preventive measures. Experience with pilot projects can be used for future.

1.13 OUTLINES OF DISSERTATION

The dissertation work in this report is presented in five chapters as follows:

Chapter 1: the different types of renewable energy sources are discussed, out of these sources ,the hydropower and hydrokinetic energy are elaborated in detail. The types and comprarison of hydrokinetic turbine are also discussed under this chapter.

Chapter 2 : an extensive literature is reviewed related to different types of hydrokinetic turbines. Investigation of working and performance parameters by various researchers reported in literature are discussed and gaps identified ,objectives, methodology and flow chart are discussed.

Chapter 3: the study of working parameters affecting efficiency and theory of hydrokinetic turbine and its model are discussed.

Chapter 4: the suitable steps are discussed for selection of hydrokinetic turbines for different sites. There are following data of different types of hydrokinetic turbines for different diameter with tip speed ratio, blockage ratio, range of Coefficient of performance, and velocity collected from different published papers . The various parameters are studied which are required to select the turbine under different field condition parameters like velocity of stream and depth of flow . Using the data studied for diameter, speed and flow velocity, a nomogram has been developed .A nomogram is a chart often used to select a suitable turbine for a particular site. It shows design parameters for hydrokinetic turbine ie diameter of rotor and speed of turbine for different turbines in the same chart. The nomogram provides assistance in determining zone sizes for larger areas.

Chapter 5 : based on the results and discussions using nomogram, conclusions are drawn and recommendation of further work is presented.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Several studies have been carried on hydrokinetic turbine in technical and scientific literature. Several researchers carried out investigations to improve performance of hydrokinetic turbine by using different augmentation techniques. The main focus was improving the performance of turbine at low rotational speed by changing the number of buckets, channel design, overlap ratio, aspect ratio etc. In this chapter, various literature and patent have studied to make a sense for the design an experimental setup in the lab and with the help of this setup turbine performance can be determined.

2.2 INVESTIGATIONS OF HYDROKINETIC TURBINE

Batista et al. [12] investigated on field test on Darrieus turbine equipped with new blade profile named EN0005 and found out that its offers self-staring characteristics without any compromise in the performance at higher TSR, and it does not required any external equipment to provide the staring torque.

Saha et. al. [13] studied at exploring the feasibility of twisted bladed Savonius rotor for power generation The twisted blade in a three-bladed rotor system were tested in a low speed tunnel, and its performance had been compared with semicircular blades. Performance analysis has been made on the basis of starting characteristics, torque and rotational speed. Performance shows the potential of the Savonius rotor with twisted blades in terms of smooth running, higher efficiency and self-starting capability as compared to that of the semicircular bladed rotor.

Mojola [15] studied the performance characteristics of the Savonius windmill rotor under field conditions. Test data were collected on the speed, torque and power of the rotor at a large number of wind speeds for each of seven values of the rotor overlap ratio. The performance data of the Savonius rotor are also fully discussed and design criteria established. Because of the difficulties inherent in selection of turbines of windmills and the large discrepancies that may arise between the test data of different workers, there is a1real need to adopt a unified method of selection of turbines not only for the Savonius windmill but for windmills in general. Under field conditions the maximum power coefficient was for an overlap ratio of about 0.25

Yuce and Muratoglu [16] studied oncurrent energy conversion (CEC) systems, the power output is directly proportional to the cubic power of the flow velocity. Therefore, in hydrokinetic systems, higher flow velocity provides higher power, called Betz limit is one of the major obstructions on the efficiency of in-stream hydrokinetic turbines. Betz law proposes that a free flow turbine cannot exceed 59.3% theoretical efficiency. However, the Betz limit can be achieved with the proper augmentation of the turbine propeller. Malipeddi and Chatterjee stated that, the power coefficient of a straight bladed-Darrieus turbine can be increased up to 0.72 with augmentation.

Talukdar et al [17] studied on the drag-based Savonius hydrokinetic turbine (SHT) has an enormous potential for small-scale power generation from free-flowing water and it can be deployed especially at sites remote from existing electricity grids. These turbines can be installed in waves, tides, ocean currents, natural flow of water in rivers, manmade channels and irrigation canals to produce power. The performance of a SHT are highly influenced by its design parameters such as blade profile, number of blades, overlap ratio and aspect ratio computational fluid dynamics (CFD) analysis.By experimentally where their maximum power coefficients are found to 0.28 and 0.17, respectively at their corresponding tip-speed ratios of 0.84 and 0.67.

Kolekar and Banerjee [18] investigated on marine hydrokinetic turbine, when operating in a shallow channel is subjected to the boundary proximity effects from a deformable free surface on top and the channel bottom. The experiments were carried out in an open surface water channel with a three bladed, constant chord, untwisted marine hydrokinetic turbine submerged at different depths and performance was evaluated under various operating conditions.

2.2.1 Effect of blockage ratio on power coefficient

At lower TSR value (1.46), blockage does not seem to have any effect on Cp as shown in the Fig 2.1.At low rotational speeds, turbine blades experience high relative angle of attack that causes flow separation on blades. An increase in blockage leads to larger effective flow velocity and increasing the relative angle of attack.

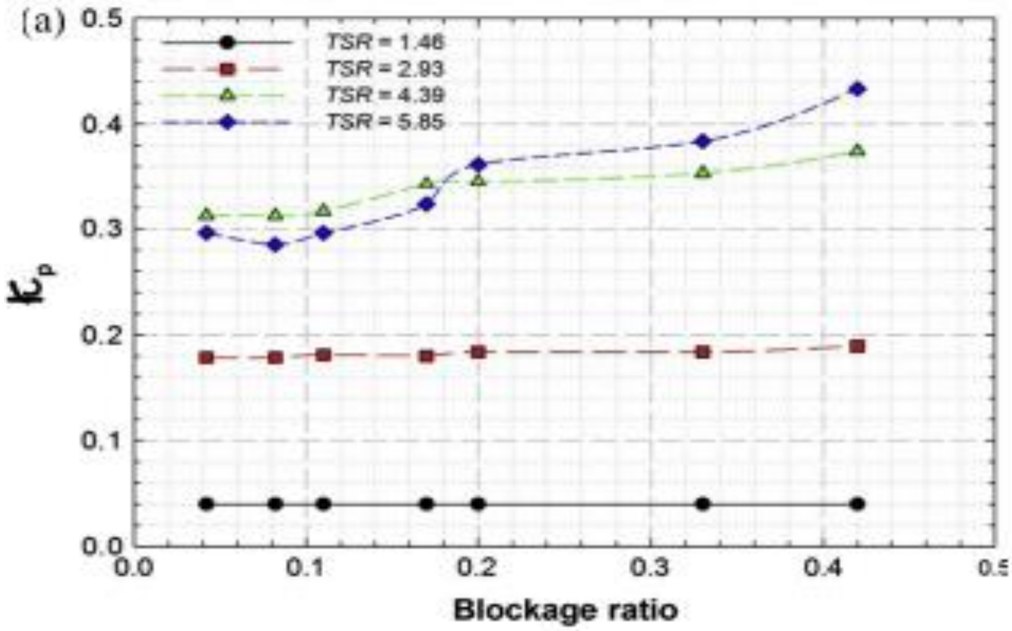

Fig.2.1 Variation of power coefficient with blockage ratio at various TSR values [18]

2.2.2 Effect of flow velocity on turbine performance characteristics.

Results from experimental and computational investigations carried out on a constant chord, untwisted three bladed MHKT are discussed. Experimental data is compared with CFD results for three flow velocities (0.5 m/s, 0.73 m/s and 0.9 m/s) for validation purpose. The results of variation of performance characteristics with flow velocity are presented in Fig. 2.2. With increasing flow velocity from 0.1 m/s, an improvement in turbine performance was observed with Cp vs. TSR curve reaching higher maxima and spreading over wider TSR range. The improvement trend continued until flow velocity reached 0.7 m/s above which no appreciable improvement was noticed.

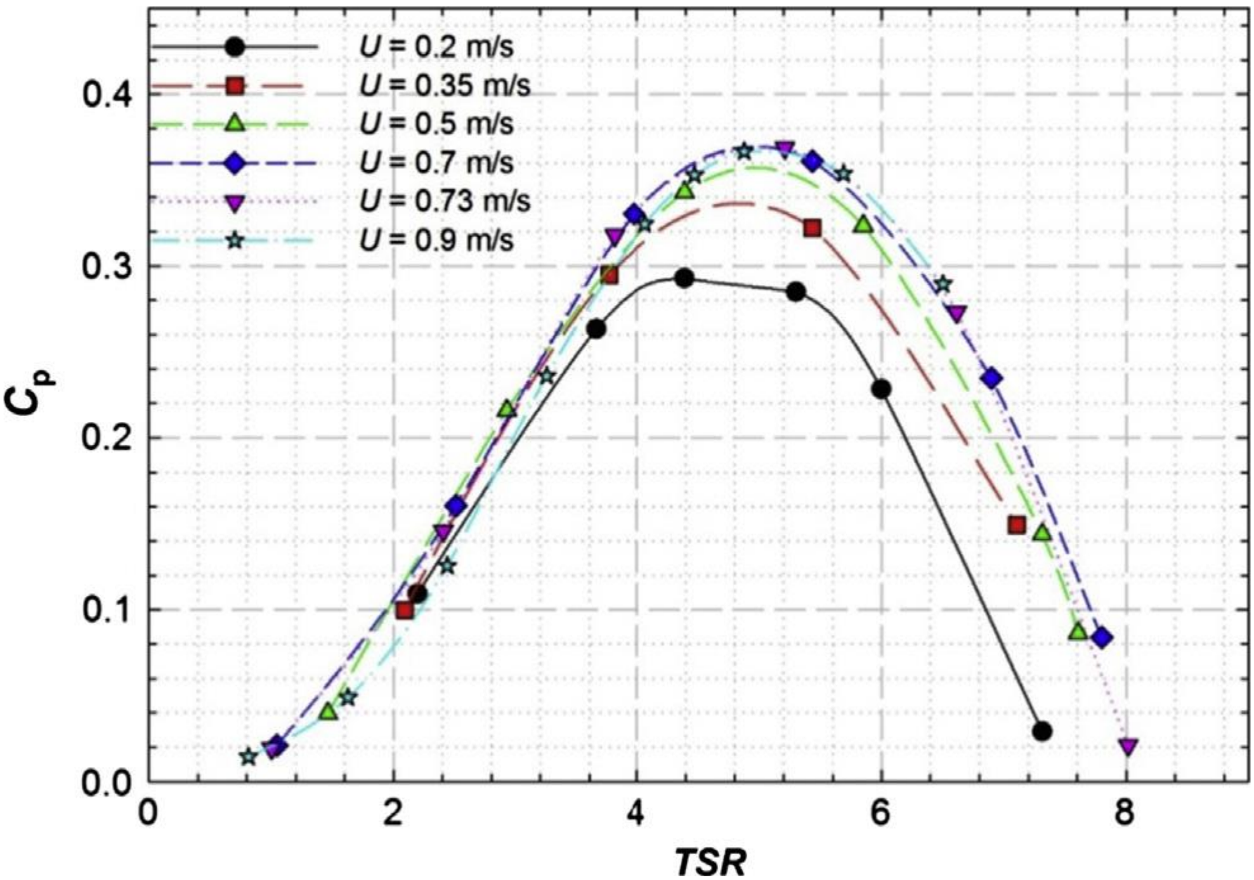

Fig.2.2. Effect of flow velocity on turbine performance characteristics.

2.2.3 Effect of blockage ratio on turbine performance characteristics.

An increase in blockage leads to larger effective flow velocity further increasing the relative angle of attack. The flow separation on turbine blades, adversely affecting its performance. Thus, blockage induces competing phenomena of elevated velocity (which increases torque) and increased flow separation (which reduces torque). At low TSR values, the improvement in turbine performance due to elevated effective velocities is nullified by flow separation effects and blockage does not cause any appreciable enhancement in power coefficient as illustrated in Fig.2.3.

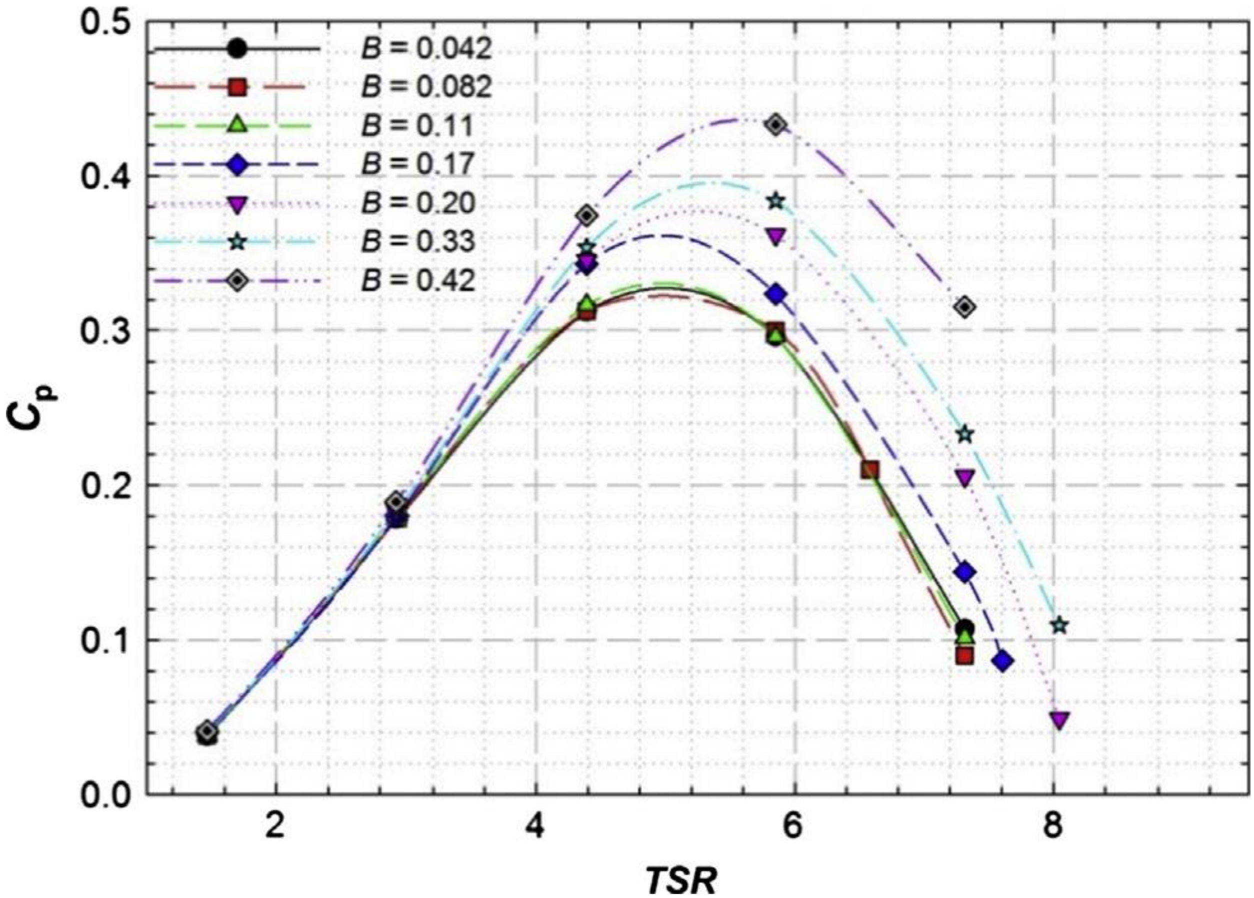

Fig. 2.3. Effect of blockage ratio on turbine performance characteristics [18]

2.2.4 Effect of TSR on percentage

increase in measured Cp (with respect to unblocked case) at various flow velocities Experimental data was then corrected according to the blockage correction presents percentage change in power coefficient between corrected and measured (raw-experimental) $\%\Delta C_p = \frac{C_{p_{measured}} - C_{p_{corrected}}}{C_{p_{corrected}}} X100$.The data presented in Fig.2.4 is from experimental runs for lab prototype corresponding to blockage ratio of 0.165. At his blockage ratio, no inflexion was for U= 0.5m/s. However,for higher flow velocities ofU=0.7m/s, the transition in Cp occurred at TSR of 5 while for U = 0.9 m/s transition occurred early, at TSR of 4.8. These points are marked by rectangles in Fig.2.4.

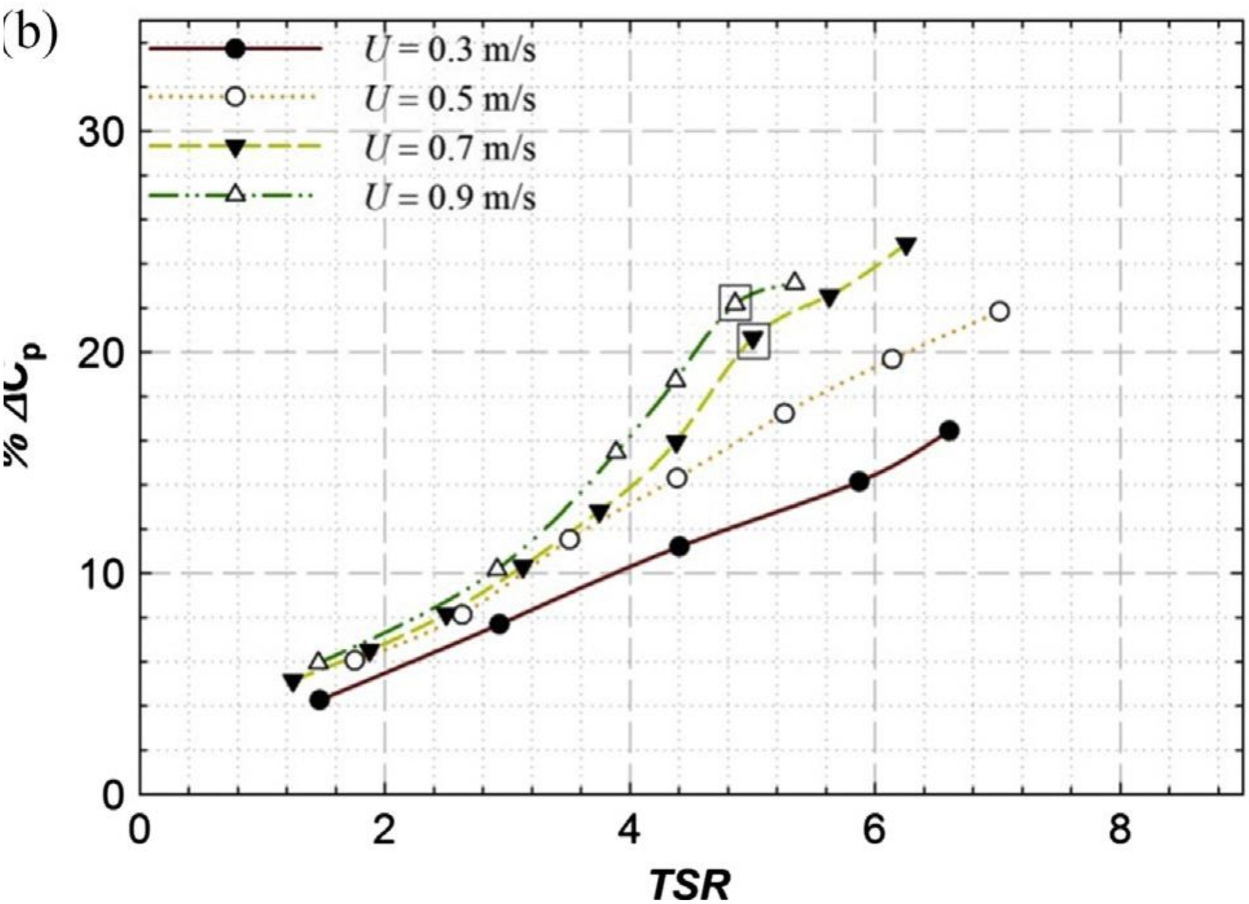

Fig 2.4 effect of TSR on percentage increase in measured Cp at various flow velocity [18].

Sharma and Sharma [19] investigated that Savonius rotor is preferred for many power gene ration applications like tidal, wind and hydro, on a small scale by virtue of its simple and inexp ensive construction, installation and maintenance. Present study is focussed on the estimation an d comparison of the performance in terms of Coefficient of Performance (COP) of a new configuration of Savonius rotor with the conventional one, using numerical simulation approach for improvement in Coefficient of Performance.

Yavuz and Koç [20] studied the hydrokinetic turbine harnesses the power from moving wat er without the construction of a dam. Operational effectiveness of the wind and hydrokinetic tur bines depend on the performance of the airfoils chosen. Traditionally, standard airfoils are used for wind and hydrokinetic turbines generating energy have the maximum lift coefficient about 1.3 at the stall angle of attack, about 12. At these values, the flow velocities to produce electric energy are 7 m/s and 3 m/s for wind turbine and hydrokinetic turbine respectively.

Qamar and Janajreh [21] studied Wind energy technology has seen steady growth in the en ergy market as a clean, renewable source of energy To improve the performance of these turbine s their design needs to be optimized. With better manufacturing methods currently available cam bered blades are being investigated to improve the performance ofthese turbinesThe study shows that low solidity turbines with cambered blades operate at low coefficients of performance (CP) over a large range of tip speed ratios (TSRs). High solidity turbines, with solidity close to unity, have much higher CP, but at smaller TSRs and a short range of TSRs. The larger chord length helps the torque production of the turbine.

Tjiu et al.[22] investigated to assess the Darrieus vertical axis wind turbine (VAWT) config urations, including the drawbacks of each variation that hindered the development into large scale rotor. They were stopped due to low economical value, i.e. high specific cost .The reliabil ity of cantilevered rotor ignited new interest in Darrieus VAWT both in small and large scale to provide better performance and lower cost of energy (COE).

Malipeddi and Chatterjee [24] developed a new duct to improve the performance of a straight-bladed Darrieus hydro turbine and it was observed that with the use of duct at tip speed ratioof 2 , torque ripple reduces by a factor of 4.15 and coefficient of power increases from 0.4 to 0.63.

Table 2.1 gives a summary of investigations carried out by various researcher as below , in this table literature reviews are summarized in the format of authors ,work done and findings.

Table 2.1: Summary of investigations carried out by various researchers

S.No.	Authors	Work Done	Findings
1	Saha et. al. [13]	At exploring the feasibility of twisted bladed Savonius rotor for power generation.	Larger twist angle is preferable in the lower wind velocity for producing maximum power and better starting characteristics.
2	Mojola [15]	The Savonius wind mill rotor under field conditions.	Under field conditions the maximum power coefficient was for an overlap ratio of about 0.25
3	Talukdar et al.[17]	The dragbased Savonius hydrokinetic turbine (SHT).	This was experimentally conducted, where their maximum power coefficients are found to be 0.28 and 0.17, respectively at their corresponding tip-speed ratios of 0.84 and 0.67. On further studied that for two-bladed semicircular SHT (with β =0.15, AR=0.7 and Do=1.1D) results in highest Cp max of 0.28 at TSR=0.89.
4	Kolekar and Banerjee [18]	Experiments carried out in an open surface water channel with a three bladed of Marine hydrokinetic turbine	Experiments carried out in an open surface water channel with a three bladed, constant chord untwisted Marine hydrokinetic turbine submerged at different depth and performance was

			evaluated under various operat ing conditions.
5	Sharma and Sharma [19]	Savonius rotor is preferre d for many power generation	Present study is focussed on th e estimation and comparison of the performance in terms of Coefficient of Performance (C OP) of a new configuration of Savonius the conventional one .
6	Wang et al. [23]	How to improve the energ y extraction efficiency (h) of wind or hydro energy	the energy extraction efficienc ies of flapping hydrofoils show tendency at first increasing and then decreasing with the in crease of maximum thickness.
7	Yaakob et al.[10]	Using CFD found the performance of a conventional two-bladed Savonius water turbine	The target function was obtain ed through varying number of tip speed ratio (TSR) from 0.2 to 1.4.

2.3 GAPS IDENTIFIED

Several studies were aimed to optimize the design parameters i.e. aspect ratio, addition of end plate, overlap ratio, gap ratio, number of blades, rotor angle, rotor stages and shape of the rotor and flow parameter i.e. Reynolds Number and these are available in literature. It is also reported that installation parameters play a critical role to enhance the performance of Savonius hydrokinetic turbine

There is a scope to investigate the effect of installation parameters techniques i.e. deflector plate, curtain arrangement, shielding arrangement, tip speed ratio and variation of the twist angle on twisted blade Savonius turbine, double and three stage hydrokinetic turbines and the free surface on twisted blade Savonius hydrokinetic turbine. In order to form a farm to scale up the electricity generation, multiple Savonius hydrokinetic turbines may be arranged in different ways.

Further there is a need for studyon the following aspects:

- Effect of installation parameters;
- Optimal sizing, installation and operation control in the field;
- Reliability, sustainability and Efficiency ;
- Techno-economic analysis of these technologies
- Effect of free surface on the performance of hydrokinetic turbines for shallow water applications.

2.4 OBJECTIVES

Based on the literature review and identified gaps as discussed above, it is found that lot of numerical and experiments investigations were carried out to improve the performance of hydrokinetic turbines, However very few studies have been reported to investigate the effect of installation parameters on coefficient of parameters

Under the present dissertation work it is proposed to develop a procedure for Selection of hydrokinetic turbines.

Keeping this in view the present study has been carried out with the following objectives.

i. To study and select the field parameters and working parameters of hydro kinetic turbine.

ii. To develop a procedure for selection of hydrokinetic turbines.

iii. To prepare a nomogram and propose the procedure for selection of hydrokinetic turbines under different conditions.

2.5 PROPOSED OUTLINE OF THE PRESENT WORK

Based on the literature review, A methodology to assess the hydrokinetic potential is developed to help the selection and the suitability of the reach for installing and operating hydrokinetic electric turbines. The methodology utilizes field measurements and two-dimensional model simulations to define the discharge, velocity, power density, turbulence, and Froude number throughout the river reach.

The various steps which are being followed in the methodology are listed below:-

a) **Study of hydrokinetic energy**

Various research papers have been studied in order to understand the concept of hydrokinetic energy and how this technology can be useful especially for rural areas.

b) **Literature review**

The reviewing of several research papers and several analytical, experimental and theoretical studies have been carried out on hydrokinetic turbines. Some pervious thesis related to the title is also studied thoroughly. Various investigations had been carried out to improve the performance of turbines. From various available cross flow turbines, Darrieus straight bladed hydrokinetic turbine is more popular for river applications.

c) **Identification of gaps**

Based on the literature review various gaps have been identify on which further investigation can been carried out to improve the performance of Darrieus turbine.

d) **Selection of installation and operational parameters**

Based on the gaps identification various parameters have been selected for present experimental work. Parameters such as Flow characteristics, water density, Flow variability in rivers, Effect of Depth variability in Rivers, tip speed ratio (TSR), Solidity (σ) etc.

e) **Study of installation and operational parameters**

The measurement and analysis approach is designed to provide base-line information needed to evaluate several critical factors, possible hydrokinetic turbine installation and operation that include:

(i) determining the location within the reach that are suitable for turbine installation by virtue of having a stable sufficient current velocity, power density and discharge.

(ii) determining thecurrent velocity and power density to ensure that turbine operation is technically and economically feasible.

f) **Effect of installation parameters on Coefficient of Performance**

Based on the literature reviews, Study and comparison of characteristic curves of installation and working parameters and effect on these on Coefficient of Performance.

(i) Characterizing river hydrodynamic conditions to be used in evaluating the effects of any future deployed turbines.

(ii) Determining the riverbed conditions that affect flow and possible turbine installation methods and operations.

g) To plot the curve between diameter and speed of turbine

In this step, the various selection curves that are prepare for each hydrokinetic turbine, data collected from the study of published papers.

h) Finalizing results and interpolation in nomogram chart

After analysis and comparing the all selection curves and its results, optimized values of various design parameters are finalized and provide suitable approaches or steps for testing and installation of hydrokinetic turbines at real site with economically and environmental friendly.

i) Dissertation writing

This dissertation is prepared inthe standard format based on installation and performance parameters on the basis of published papers.

The various steps which are followed in the methodology are listed in flow chart Fig 2.5:-

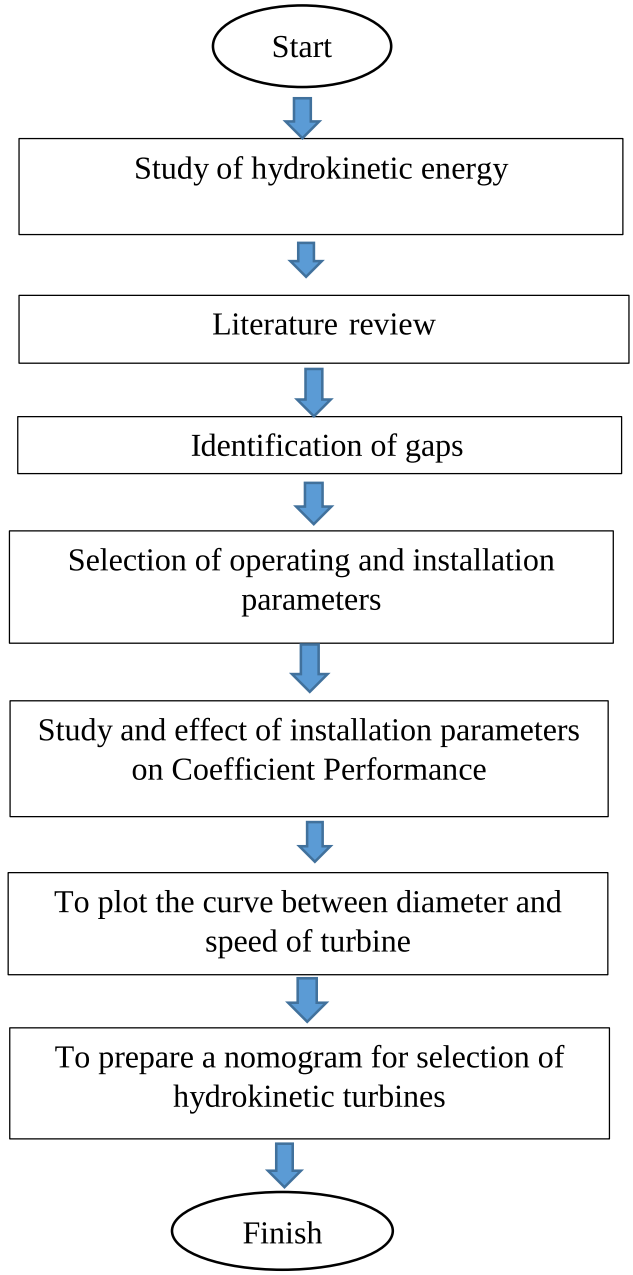

Fig. 2.5 : Flow chart

CHAPTER 3

HYDROKINETIC TURBINE

3.1 GENERAL

Hydrokinetic turbine is the energy possessed turbine by the moving water. Hydrokinetic energy conversion systems are the electromechanical devices that convert kinetic energy of river streams, tidal currents, man-made water channels or waves into electricity without using a special head and impoundment. Hydrokinetic conversion system produces electricity by making the use of flowing water contained in river streams, tidal currents, or other man made water ways. Producing power from the speed of water is what distinguishes hydrokinetic energy from conventional hydropower plants.

3.2 EFFICIENCY RESENTATION AND WORKING PARAMETERS AFFECTING EFFICIENCY

Hydrokinetic was originally developed to surmount the numberless of problems associated with dams throughout the world. This system in erected into the river or stream which results in compared to the traditional hydropower:

i. No dam is required
ii. There is no destruction of nearby land,
iii. No change in the river flow regime,
iv. Reduction of flora and fauna destruction.

The terms hydrokineti is utilized for both tidal river applications. In this progress report, the f ocus is on river application, since it is suitable for energy generation at remote and isolated loc ations.

Efficiency

It can be defined as ratio of output shaft power of turbine to the inlet kinetic energy of water per unit is known as efficiency of the hydro kinetic turbine.

$$\eta = P/ (1/2)\ \rho \times A \times V^3 \qquad (3.1)$$

Where, P = Mechanical power available at turbine shaft, ρ = density of the working fluid, A = H *D Rotor Area, H = Height of the turbine blade, V= velocity of flowing streams.

$P = T*\omega$

T = Mean torque available at the turbine shaft, ω = Angular velocity of blade.

Various parameters which plays an important role for performance testing of Darrieus turbine ar e discussed below:-

a) **<u>Solidity</u> (σ):** It is defined as ratio of effective area occupied by the blade to the total frontal area of the rotor.

   $\sigma = nC/ \pi D$ (3.2)

   Where, n = number of blades, C = Chord length of the blades, D= Diameter of Darrieus turbine rotor.

b) **Tip speed ratio (TSR):** It is defined as the ratio of peripheral velocity of the rotor to the free stream velocity of water.

   $$\mathrm{TSR} = \frac{R\omega}{V} \quad (3.3)$$

   Where, ω is Angular velocity of Turbine blade, R is Radius of the blade, V is Water flowing speed.

c) **Blockage ratio (BR):** it is defined as the ratio of the area covered by the rotor of the turbine to the projected flow area in the water channel.

   $$\mathrm{BR} = \frac{H\ D}{\mathrm{Hw\ Ww}} \quad (3.4)$$

   Where, Hw = Height of water depth in channel, Ww = width of the water channel.

d) **Aspect ratio (AR**): It is defined as the ratio of height of the turbine blade to the diameter of the blade.

   $$\mathbf{AR} = \frac{H}{D} \quad (3.5)$$

This is very important criterion for the evaluation of the hydro kinetic turbine. Aspect ratio is shown in Fig.4.1.

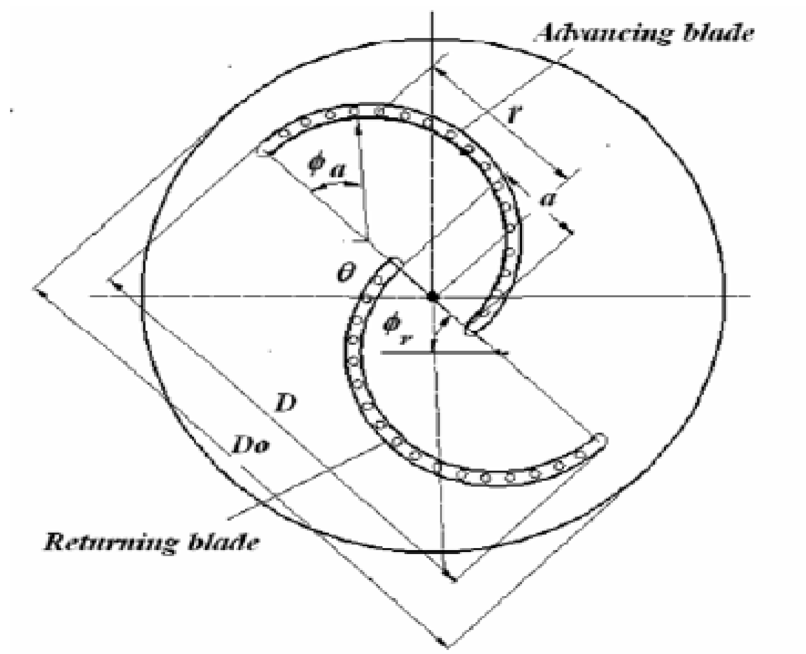

Fig. 3.1: A typical two bladed Savonius rotor

a) **Angle of attack (AOA):** Angle between water speed and the cord line of the airfoil is called angle of attack. In case of rotating blade the angle of attack measured between the water speed and the cord line in Fig 3.2.

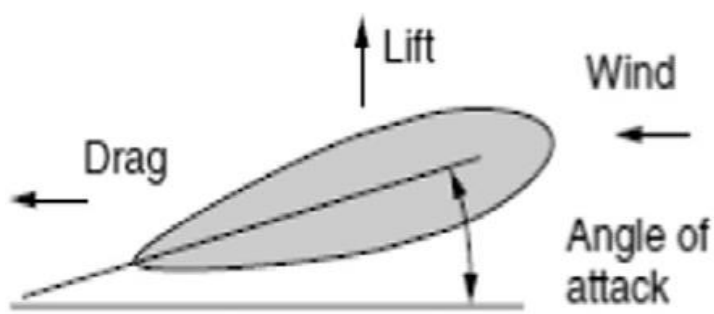

Fig. 3.2: Angle of attack

3.3 THEORY OF HYDROKINETIC TURBINE AND PERFORMANCE COEFFICIENT

Tidal and river stream energy technologies are in the early stages of development with various generating systems currently being researched. Many different basic turbine configurations have been reviewed in literature and their generating efficiency has been assessed.

Kinetic energy passing unit time

$$P_0 = (\rho A_1 U_0) * U_0^2/2 = \frac{(\rho A_1 U_0^3)}{2} \qquad (3.6)$$

Water density depends weakly on salt content. Area A1 is the rotor swept area. The only flow is across the ends of the stream tube. The turbine is represented by a uniform 'actuator disc' which creates a discontinuity of pressure in the stream tube of water flowing through it as shown in Fig 3.3 and Fig 3.4 [11].

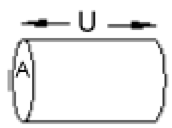

Fig3.3 Kinetic power in water stream.

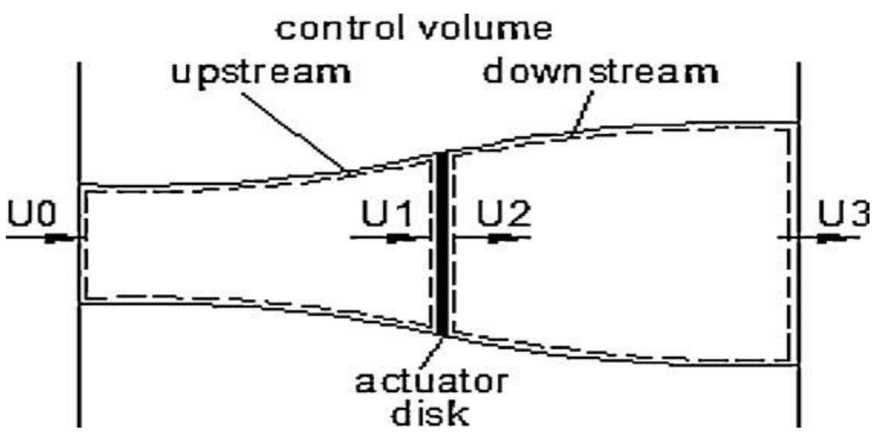

Fig.3.4Actuator disc model of a water current turbine.

The following assumptions were made in this analysis

a. no frictional drag;
b. homogenous, incompressible, steady state fluid flow;
c. an infinite number of blades;
d. uniform thrust over the disc or rotor area;

e. a non-rotating wake;

f. the static pressure far upstream and far downstream of the rotor is equal to the undisturbed ambient static pressure.

The theory proceeds by considering supposed constant velocity water stream lines passing through and by the turbine in laminar flow, Fig. 3.4. From the applying the conversation of linear momentum to the control volume, the thrust is equal and opposite to the rate of change of momentum of the wate stream.

$$T = U_o\,(\rho AU)_o - U_3\,(\rho AU)_3 \qquad (3.7)$$

The equation m˙ = (AU)o = (AU)3 may be written for steady state flow. Therefore:

$$= \text{m}\,(U_o - U_3) \qquad .(3.8)$$

The Bernoulli equation may be used on either side of the actuator disc.

For the upstream side:

$$\text{P}_\text{o} + \frac{1}{2}\,\rho U_2^2 = P_3 + \frac{1}{2}\,\rho\,U_3^2 \qquad (3.9)$$

For the downstream:

$$P_2 + \frac{1}{2}\,\rho\,U_2^2 = P_3 + \frac{1}{2}\rho\,U_3^2 \qquad (3.10)$$

The pressures P_O and P_3 can be assumed equal, and the velocity (U1 =U2) on the both side of the disc remains the same. Another expression of the thrust can be of the forces on both side of the disc:

$$\text{T}=A_1\,(P_1 - P_2)\ldots \qquad (3.11)$$

One can find the difference p2 −p3 by using Eqs. (3.8) and (3.9) and substitutes to Eq. (34.11), and then the following equation is obtained

$$T = \frac{1}{2}\,\rho\,A_1\,(U_0^2 - U_3^2\,) \qquad (3.12)$$

$$\text{m}^{\cdot} = A_1 U_1 \qquad (3.13)$$

Hence

$$U_1 = \frac{U_0}{2} + \frac{U_3}{2} \qquad (3.14)$$

That means, the water velocity at the rotor plane is the average of the upstream and downstream water speeds. If one defines the interference factor, a, as the fractional in water speed between the free stream and the rotor plane then

$$a = \frac{U_{0-}\ U_1}{U_0} \qquad (3.15)$$

$$U_1 = (1 - a)U_0\ldots \qquad (3.16)$$

Using (3.9)

$$U_3 = (1 - 2a)U_0 \quad (3.17)$$

Power (P) can be obtained by water velocity time the thrustvalue:

$$P = \frac{1}{2} \rho A_1 (U_0^2 - U_3^2)U_1 = \frac{1}{2} \rho A_1 U_1 (U_0 + U_3 \quad (3.18)$$

One substitutes U1 and U3 from Eqs. (3.16) and (3.17) into Eq. (3.18).
Therefore:

$$P = \frac{1}{2} \rho A_2 U_0^3 \, 4 \, a(1 - a)^2 \quad (3.19)$$

If A2 is replaced by A and U0 is replaced by U, then:

$$P = \frac{1}{2} \rho A U^3 4 \, a \, (1 - a)^2 \quad (3.20)$$

The performance coefficient is defined rotor power per power in the water. Hence

$$C_P = \frac{P}{\frac{1}{2} \rho A U^3} = 4a(1 - a)^2 \quad (3.21)$$

The derivatives of performance coefficient respect to and setting it equal to zero, gives the maximum C_P value of 0.59.

The theoretical maximum power available from the river and marine current is expressed by the equation above using a performance coefficient of 0.59, or 59% efficiency. But a small-scale river turbine has its own losses which will reduce coefficient to around 0.10–0.25. The significant aspect to equation that the power increases in a cubed relationship to the velocity of the flow of water past the turbine. Therefore, it is important to find the best flow get the best power output.

3.4 PERFORMANCE

There are 6 major aspects to be considered while determining the performance:-

i. Water Power
ii. Power Generation
iii. Power Conversion Efficiency
iv. Power Conversion Reliability
v. Operations and Maintenance Costs
vi. Finance Options.

3.5 AREA OF APPLICATION

Followings are the types of sites for hydrokinetic turbine includes:-

i. Ocean wave
ii. Tidal stream
iii. River stream
iv. Ocean current and
v. Irrigation and other manmade canals.

Out of these there are only three main areas where hydrokinetic devices can be used in power generation purposes are, (1) tidal current, (2) river stream and (3) irrigation and man-made canals. Ocean current represent another potential source of ocean energy where the flow is unidirectional, as opposed to bidirectional tidal variations. In addition to these, other resources include,manmade channels, irrigation canals, and industrial out flows [7].

3.6. HYDROKINETIC TURBINE MODEL

The developed model is based on the steady-state power characteristics of the hydrokinetic turbine. The output power of a hydrokinetic turbine is given by

$$P_m = 0.5\rho\pi\, r_2 v_3 C_p(\lambda,\beta)\ldots \quad (3.22)$$

where P_m is the power, ρ is the water density(997 kg/m3 at 25 °C), r is the blade radius(m), v is the water velocity(m/s), C_p is the power coefficient of the hydrokinetic turbine, λ is the tip speed ratio and β is the pitch angle of the turbine. Therefore, if the water density ρ, blade radius r and water velocity v are constant, the output power P_m is proportional to the power coefficient C_p which is determined by the value of λ and β. However, for a fixed pitch angle hydrokinetic turbine which is the main interest of discussion in this thesis, the power coefficient is only determined by λ.

Therefore, the output power of a hydrokinetic turbine is given by

$$P_m = 0.5\rho\pi\, r_2 v_3 C_p(\lambda) \quad . \quad (3.23)$$

The tip speed ratio of a hydrokinetic turbine is defined as

$$\lambda = \frac{r\omega_m}{v} \quad (3.24)$$

where r is the blade radius(m), v is the water velocity (m/s), and ω_m is the rotational speed of the hydrokinetic turbine(rad/s).

Based on the hydrodynamic analysis of the hydrokinetic turbine used in this hydrokinetic project, a simplified relationship between Cp and λ when the pitch angle is 12 degree is given by

$$C_p = \frac{16}{27}\lambda\left(\lambda + \left(1.32 + \frac{\left(\frac{\lambda - 8}{20}\right)^2}{B^{0.667}}\right)\right)^{-1} - \frac{0.57\lambda^2}{C(\lambda + 0.5B)} \tag{3.25}$$

where B is the number of blades of the hydrokinetic turbine, which is 3, and C is the ratio of lift coefficient, C_l, to drag coefficient, C_d, which is 30. All of the turbine parameters are based on the hydrodynamic analysis of the hydrokinetic turbine that will be used in this project. Based on above Eqn the C_p-λ characteristic of the hydrokinetic turbine is shown in Fig. 3.5. [35].

The maximum value of C_p is 0.395 which is achieved at λ=5.2. Figure 3.5 gives the characteristics of the hydrokinetic turbine power coefficient C_p for different values of water speed where V1=1 m/s, V2=0.9 m/s, V3=0.8 m/s, and V4=0.7 m/s. The maximum turbine output power $P_{m\_maximum}$ under different water velocities is achieved at different rotational speed as shown in Fig 3.6.

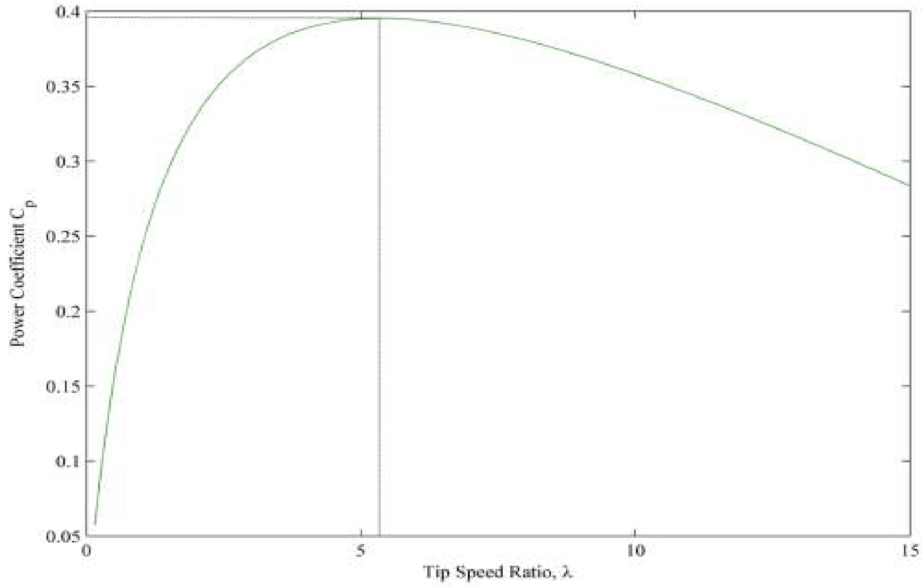

Fig. 3.5. C_p-λ characteristic of the hydrokinetic turbine [44]

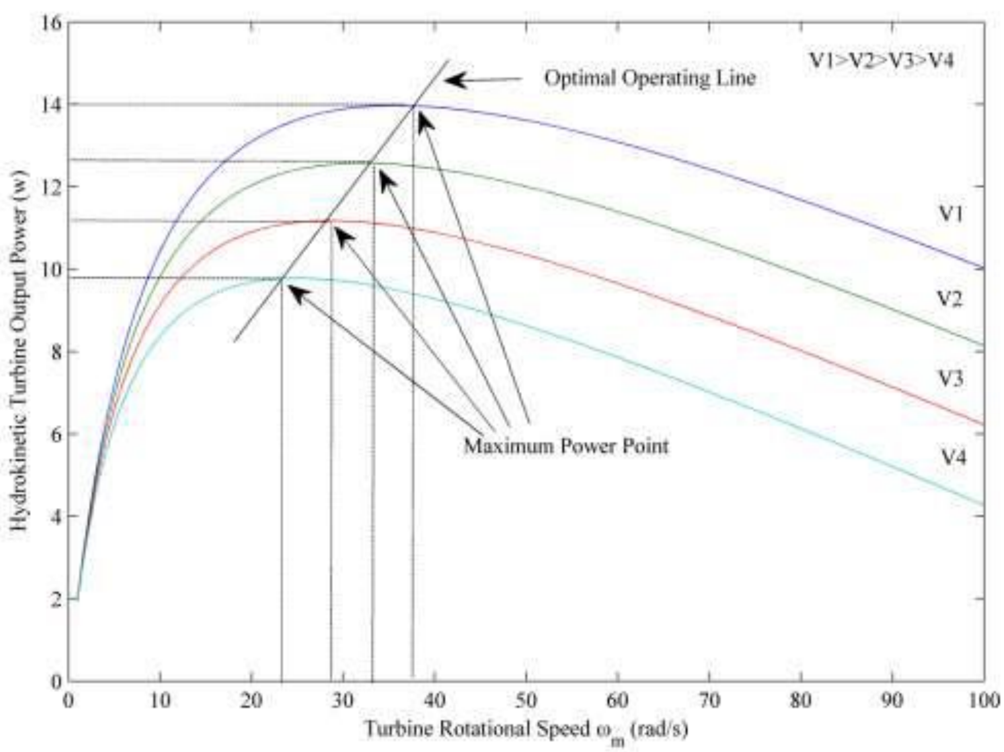

Fig 3.6 w-ω_m characteristic of the hydrokinetic turbine at different water speed [44]

CHAPTER 4

SELECTION OF HYDROKINETIC TURBINES

4.1 GENERAL

The aim selection of right system is to verify contractual guarantees in terms of power best operating range and coefficient of performance. These guarantees shall be verified under contractually defined condition (aspect ratio, tip speed ratio, overlap ratio, gap ratio and flow parameters i.e. Reynolds number, flow variability in river, velocity and turbulence, disturbance etc.)

While all hydrokinetic devices operated on the same conversion principles regardless of their areas of application, a set of subtle differences may appear in the forms of design, operational features and site condition parameters. Some operational parameters are discussed earlier and Design and Field condition parameters are described below;

Various investigations had been carried out to improve the performance of turbines. From various available cross flow turbines, Darrieus straight bladed hydrokinetic turbine is more popular for river applications.

4.2 STEPS FOR SELECTION OF HYDROKINETIC TURBINES

The suitable approaches or steps required for selection of hydrokinetic turbines at different site are as follows;

Step 1: Site Identification and Assessment

First step is to identify the site and analyze the Hydrokinetic potential assessment criteria. In this step, there are necessity to determine the importance of specific site assessments for a given project.

i. **Site** – For the placement of hydrokinetic devices is to take care the geophysical characteristics of a site potential and the city or village where implementation has been proposed. The installation of hydrokinetic turbine should be site specific and a specified and tested location for turbine deployment should have the specific characteristic. In this step ,it is also required to analyze the properties of sediment particle which includes the particle size d, specific gravity ,fall size, shape factor and bed forms.

There are three categories of resource estimates primary information;

- Theoritical resource :It denotes the total annual hydrokinetic potential available
- Technical resource: In this the energy that can be extracted by hydrokinetic energy conversion technology and
- Practical resource: The energy that can be extracted considering all practical factors [Use HEC technology ,user conflict (such as maintaining shipping routes) and debris mitigation (such as logs and sediment)]

Hydrokinetic energy sources are classified in different ways, including off shore and inland generation. Offshore generation harnesses wave power and tides from coastal bodies of water such as oceans and seas. Inland generation is composed of run-of-river and in-stream tidal energies, both are separated from the intensity of offshore areas. There is abundant potential for harnessing energy within inland areas because (a) it is easier to deploy equipment in these environments compared to those offshore, and (b) are more closely related to hydroelectricity currently being produced by other types of hydropower plants since all of these are in-land systems, i.e. impoundment dams, diversion method [7].

ii. Types of Inland Hydrokinetic Systems

Inland hydrokinetic energy systems are categorized as either run-of-river or in stream tidal systems. Run-of-river systems harness energy from the unidirectional flow of surface water and utilize ultra-low head height turbine systems. Although run-of-river systems exploit the potential energy from a differential head height in flowing water, they nonetheless differ from conventional hydropower. In-stream tidal systems are inland systems within saltwater bays or estuaries connected to the ocean.

In-stream tidal systems must be able to harness flow from two directions (due to tidal flows) to convert the most kinetic energy possible into useable electricity. In stream tidal systems capture tidal energy that moves into an inlet, which acts as channelized flow; such systems convert both the tidal energy and the natural in stream flow of the inlet into electricity.

Step 2: Water Resources Characteristics

Collection of data which are useful for selection of turbine such as installation parameters and operational parameters and these various parameters are selected for present work .Parameters such as flow characteristic, water density, flow variability in river effect of depth variability in river,tip speed ratio (TSR) , blockage ratio and solidity.

i. **Water Resources**:- The water resources are the basis of why certain sites are chosen for further assessment rather than others. The velocity of the water in the area of deployment is directly proportional to the amount of energy that can be captured. Also, the devices used at the sites are usually chosen based upon the velocity and the amount of area available for placement. The cross-sectional area helps to model the space that can be utilized for turbines; this helps estimate research deployments and full capacity deployments within each site.

ii. **Flow Characteristics and Variability**:- The flow characteristic of a river stream is significantly different from tidal variations. The forecasting of flow conditions is more engaged for river application and many geographic places may not have such agreements. The energy output level is directly linked to the flow velocity for a hydrokinetic converter. While the former has a powerful stochastic (seasonal to daily) variety, the latter undergoes fluctuations of dominant periodic (diurnal to semidiurnal) nature. Furthermore, for these two instances, the phase of a stream may have different profiles.

iii. **Water Density**: Sea water density is higher than fresh water density. It implies that less power generation capacity for tidal turbine when placed in a river stream .In addition depending on level of salinity and temperature, sea water may have different energy content at different location and time.

iv. Velocity and Turbulence, Disturbance and Magnitude:

Over periods of steady or quasi-steady flow, Neary and Sale (2010) showed that vertical profiles of velocity and Reynolds stresses generally follow classical laws if large roughness effects and obstructions that perturb boundary shear flows are absent. The no-slip condition requires that the turbulence intensity and all components of the Reynolds stress tensor are zero at the bottom of a fixed boundary, but field measurements are currently limited within the near wall region, even with state-of-the-art acoustic instruments, and rivers typically have mobile beds with non-zero mean velocity and Reynolds stresses.

v. **Effects of Depth Variability in Rivers:**

The effects of large depth variability on the location of the energy extraction area and its centerline relative to the velocity and turbulence characteristic profiles. Two river hydrokinetic devices at sites with a large range of seasonal depth variability are compared to a tidal site where depth variability is much less pronounced. The centerline and height of the energy extraction plane is also non-dimensionalized with D, which causes the centerline and height to decrease with greater depth. In theory, the normalized velocity and turbulence distributions would remain unchanged with depth and flow changes. Therefore the additional variation in velocity and turbulence that a device will experience over its design life as a result of moving up and down the relative depth z/Das shown in Fig 4.1. This is a consideration whenever the characteristic length scales of the hydrokinetic extraction device are on the same order as water depth.

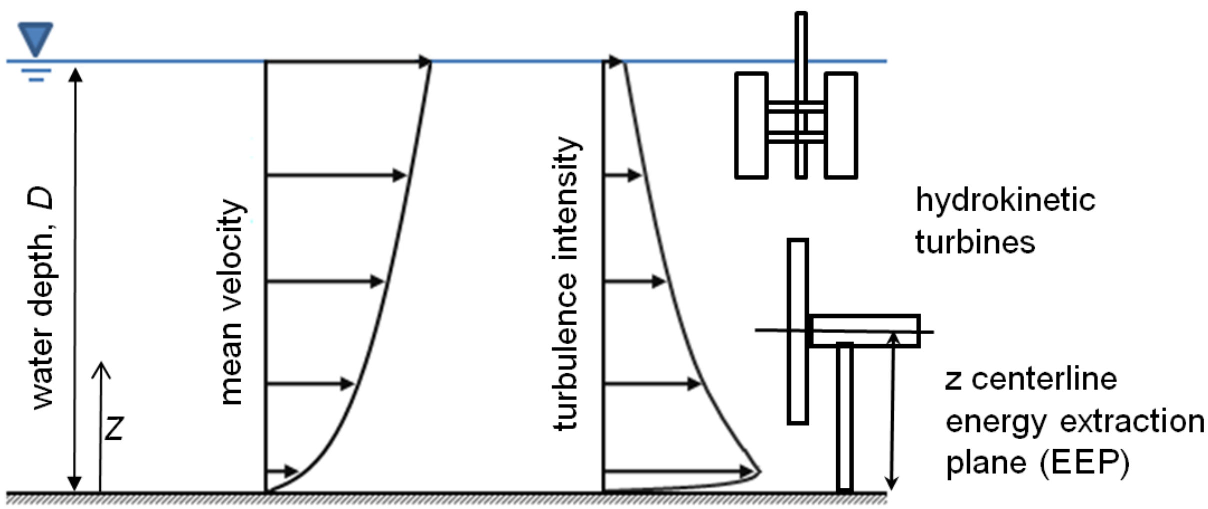

Fig 4.1 Typical distributions of velocity and turbulence [47]

vi. **Temperature Density and Viscosity**

Water temperature T [θ], density ρ [ML-3] and kinematic viscosity ν [L2T-1] are all important fluid properties that must be measured and reported for resource characterization. For freshwater, density and viscosity are dependent directly on temperature Therefore, only the water temperature has to be measured coincidental with the flow measurements in fresh water.

vii. **Directionality:**

River flow is unidirectional and this eliminates the requirement for rotor yawing. In tidal stream, a turbine may operate during both flood and ebb tides,if such yaw/ pitch mechanism is in place.

Step 3: Selection of measuring Instruments

Selection of different measuring instruments to measure field condition parameters such as current velocity by use of current meter, discharge of flow by velocity area method in river and canal. Model velocity and specific discharge values are exported to a spreadsheet to calculate the maximum velocity and maximum specific discharge at each cross section along the river reach that are of specific interest in determining the location of maximum hydrokinetic power in the river.

Step 4: Selection of turbines

Selection of turbine on which testing will be conducted and selection of appropriate generator based on speed of turbine. In this steps the selection curves are plotted for each hydrokinetic turbine based on the data collected from study of papers.

4.3 DESIGN OF SIZE OF DIFFERENT HYDROTURBINE FOR MAXIMUM PERFORMANCE

The design of rotor is done to obtain maximum coefficient of performance and without occurrence of cavitation at the operational point. Considering the river depth, stream velocity and the available manufacturing technology, a rotor diameter of hydrokinetic turbine are selected and developed using performance parameters which are TSR, Velocity and blockage ratio and speed of generator available in market.

Obtained performance parameters data and diameter of different turbine is based on published paper

4.3.1 Savonius Turbine

The Savonius rotor's operating principle is based on the distinction in drag force between the concave and convex section of rotor blade when rotating around a vertical shaft. The concave surface drag coefficient is more than the convex surface coefficient. Many scientists suggested that the savonius turbine can operate at low velocity because it has low starting torque as it is easy to build and low price recommend using savonius turbine for power generation as well as being very easy to combine with generator makes it easy to maintain. Fig 4.2 shows a typical two bladed Savonius rotor. According to Savonius, the best of his rotor had a maximum efficiency of 31% while the maximum efficiency of the prototype was 37% [50].

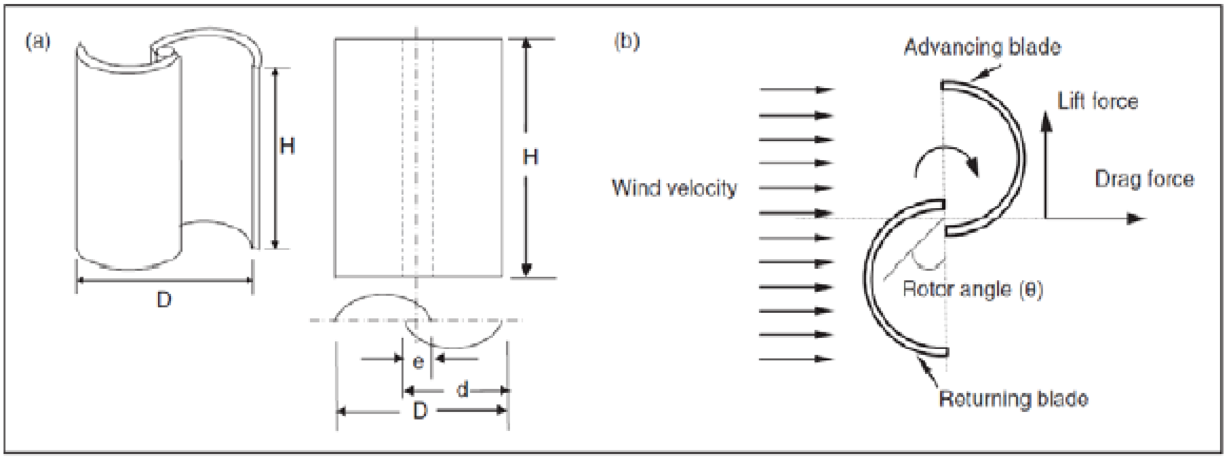

Fig 4.2 : (a) Two bladed Savonius rotor (b) Effect of drag forces acting on this rotor [49]

(i) Design parameters data of Savonius hydrokinetic turbine

Savonius hydrokinetic turbine is similar to Savonius wind rotor; so design or geometrical parameters i.e, gap ratio, end plates,overlap ratio, aspect ratio the number of rotors , blade profiles ,the number of rotor stages, , etc. are the main suitable parameters that affect the performance of a Savonius hydrokinetic turbine.

In order to develop the performance of rotor, researchers optimized these design parameters experimentally or numerically. Collection of data from different research papers as given in Table 4.1.

Other than these geometrical parameters, installation parameters i.e. direction of rotation axis (CW/ACW) clearance ratio can affect the performance of Savonius hydrokinetic turbine. Effect of TSR and blockage rario parameters are considered and data are taken from published papers as given in Table 4.1.

Table 4.1: Installation data for savonious turbine obtained from published papers

Diameter of turbine(m)	Number of blade	TSR range	TSR Optimum	BR	Velocity range	Velocity (m/s)	R P M	C_P range	C_P max	Reference
0.14	2	0.55-1.8	1.2	0.187		0.85	139.21	0.02-0.3	0.3	25
0.15	2	0.3-1.2	1.1	0.06		0.7	98.90	0.1-0.2	0.2	26
0.16	2	0.5-1.0	0.95	0.12	0.5-2	1	113.45	0.19-0.39	0.39	09
0.25	2	0.4- 1.35	0.89	0.07	0.1-6.1	0.8	54.42	0.03-0.28	0.28	17
0.26	3	0.625-1.0	0.77	0.21	0.3-0.9	0.9	50.93	0.1-0.4	0.4	27
0.27	2	0.6-1.1	0.7	0.21		0.4	19.81	0-0.15	0.15	34
0.3	2	0.2-1.2	0.6	0.19		0.46	17.5796	0-0.2	0.2	26
0.4	2	.05-.8	0.4	0.24	0.77-1.22	1.25	23.8854	.02-0.13	0.13	28

(ii) Plot a curves of Savonius turbine

This plot shows the curve of diameter of turbine versus tip speed ratio for savonious turbine and data are collected from published paper. Objective of this Fig 4.3,the curve is to determine a suitable range of diameter of savonious hydrokinetic turbine based on tip speed range and coefficient of performance of turbine.

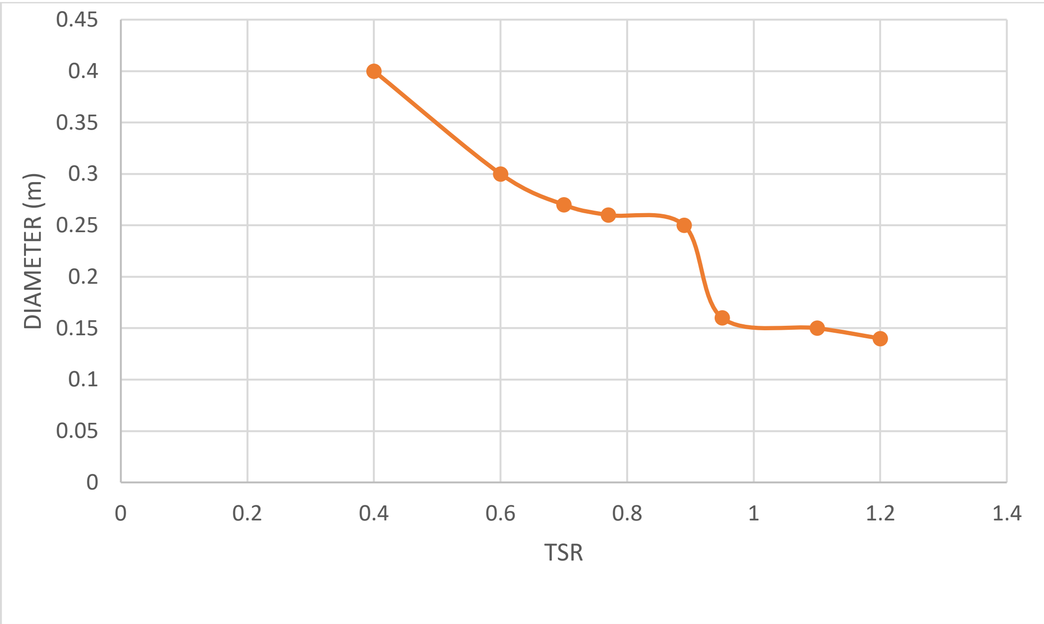

Fig 4.3 Variation of Diameter with respect to TSR for selection study of Savonious turbine

According to available data maximum value tip speed ratio of savonious turbine is 1.2 with range of .5 to 1.8 for diameter of .14 meter. This curve denotes that suitable diameter of .14 meter for optimization tip speed ratio and coefficient of performance.

The diameters of the turbine is developed as represented by equation 4.1.

Equation Of Curve

$$\text{Diameter, D } y = 0.156x^2 - 0.5775x + 0.6025 \quad (4.1)$$

Based on the data available in papers , an attempt has been made to validate the numerical result of diameter of rotor and speed under maximum Coefficient of Performance of savonious turbine by using tip speed ratio, solidity ratio, blockage ratio and speed of flowing water.

It is clear that when free stream velocity is approximately same for different sites then diameter of savonious turbine increases, speed of turbine decreases and vice-versa but when free stream velocity is variable at sites or in seasonaly then speed of turbine is also variable for same diameter.

In Fig 4.4 for 150 mm of diameter of savonious turbine, speed is 98 rpm at free stream velocity of 0.7 m/s with maximum value of coefficient of performance of 0.2 but for 160 mm dia , the speed is 113 rpm at stream velocity of 1 m/s with maximum value of coefficient of performance of 0.39 , mainly due to increase in free stream velocity from 0.7 to 1 m/s.

Hence Fig 4.4 shows that the maximum coefficient of performance occurs at 115 rpm for 160 mm diameter of rotor. Finaly it is conclude that savonius turbine should be operated for the range of free stream velocity of 0.4 to 1.25 m/s for testing at different sites .

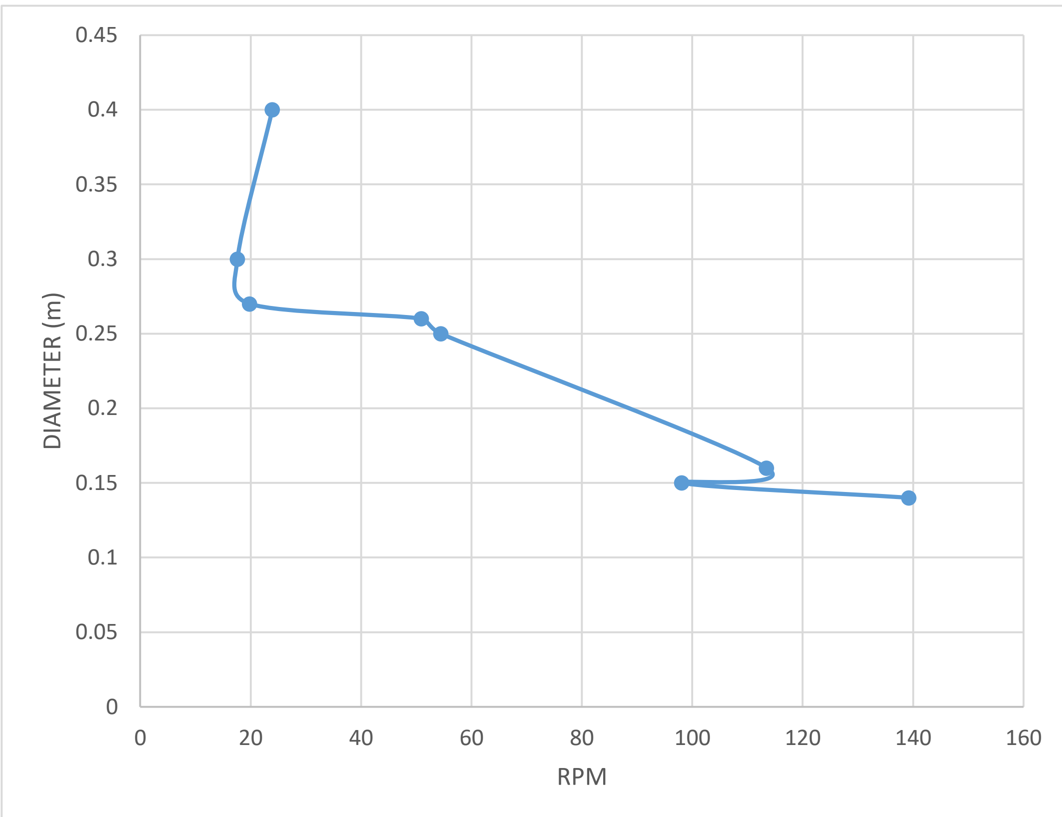

Fig 4.4 Variation of Diameter with respect to Speed in rpm for selection study of Savonious turbine

Further attempt has been made to develop a correlation for diameter of turbine and speed as given in Equation 4.2.

Equation of Curve

Linear model Poly 3:

$$y = 3E\text{-}07x^3 - 6E\text{-}05x^2 + 0.0019x + 0.2702 \qquad 4.2$$

4.3.2 Axial flow Turbines

Those turbines which have their rotating axes parallel to the direction of entering water are called horizontal axis turbine. These turbines are also known as axial flow turbines.

Inclined axis turbines are mostly studied for small river energy converters. Axial flow turbines are common in tidal energy and are very similar to modern day wind turbines from concept and design point of view. Turbines with solid mooring structures require the generator unit to be placed near the riverbed. Horizontal axis rotors with a buoyant mooring mechanism may allow a non-submerged generator to be placed closer to the water surface.

When these axial flow turbines are operated in the same water flowing conditions then these may reach higher efficiency compare to cross flow turbines. if these are operated in slow water current ,then they can self-start, however their manufacturing and transportation cost is higher due to various factors given below.

a) These turbine requires water sealed components like generator, gearing and bearing etc, which involves more cost and maintenance.
b) The airfoil shape of the blades is costlier to manufacture
c) These turbines are difficult to transport because their blades size are usually large.

Effect of TSR and blockage ratio parameters are considered and datas are taken from published papers shown in Table 4.2.

Table 4.2: Data for Axial flow hydrokinetic turbine obtained from published papers

Diameter of turbine(mm)	Number of blade	TSR range	TSR Optimum	Velocity range	Velocity (m/s)	Cp range	C_P Max	Speed (RPM)	Reference
280	3	0.8-8.0	5.2	0.2-0.9	0.73	0.02-0.38	0.38	259.05	18
500	2	4.0-9.0	7	1.0 2.0	1.26	0.2-.45	0.45	337.07	29
675	3	1.8-6.0	5		1.7	0.1-0.4	0.4	240.62	30
700	3	0.5-3.8	4	1.0-1.7	1.5	0-0.35	0.35	163.78	31
1500	2	4.0-9.0	6.5	1.0-2.0	1.26	0.3-.45	0.45	104.33	
3000	3	0-12	7		1.73	0-0.45	0.45	77.13	32

This plot diameter of turbine vs tip speed ratio for Horizontal axis hydrokinetic turbine and data are collected from published paper. Objective of Fig 4.5, the curve is to determine a suitable range of diameter of Horizontal axis hydrokinetic turbine based on tip speed range and coefficient of performance of turbine**.**

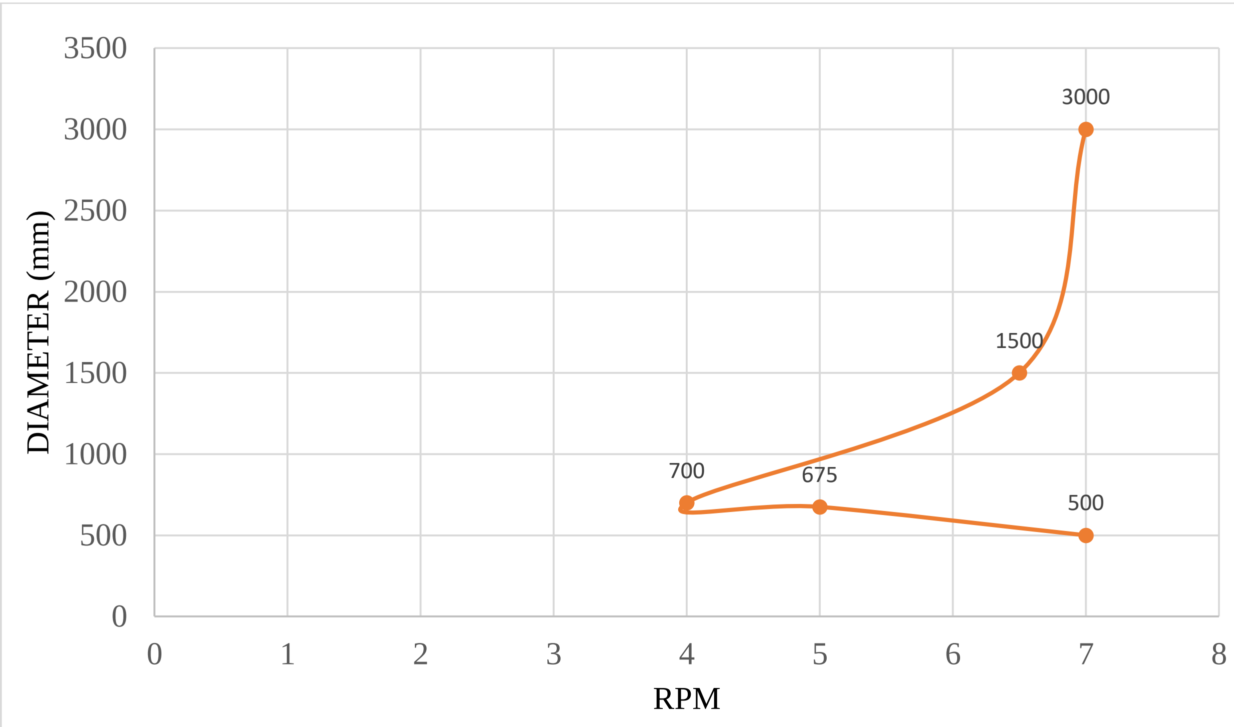

Fig4.5 Variation of Diameter with respect to TSR for selection study of horizontal axis hydrokinetic turbine

It is clearly seen from Fig 4.4 in case of horizontal axis for minimum diameter turbine ,when dia increases TSR value decreases because of dominant of free stream velocity but for larger diameter turbine ie diameter from 700mm to 3000mm ,when the diameter increases[22] then TSR value increases. So the evaluated turbine design was predicted to obtained a maximum coefficient of performance of 0.4642 at TSR =6.

The correlation is developed between the diameter of turbine as a function of speed as given in equation 4.3.

Equation of curve

Diameter ,$y = 0.2695x^2 - 2.5868x + 6.7143$ 4.3

Objective of Fig 4.6, the curve is to determine a suitable range of diameter of Horizontal axis hydrokinetic turbine based on speed in rpm and maximum coefficient of performance of turbine**.** In above Fig 4.5, the graph shows when diameter of horizontal axis turbine increases then speed of rotor decreases with in limit variation of free stream velocity, but for high variation of stream flow velocity when dia increases then speed also increases for example in above graph when diameter increases from 280mm to 500mm then speed also increases because of increment of free stream velocity from .73 m/s to 1.26 m/s .so for lower diameter turbine slightly variation of stream velocity suddenly effect on variation of speed of rotor .

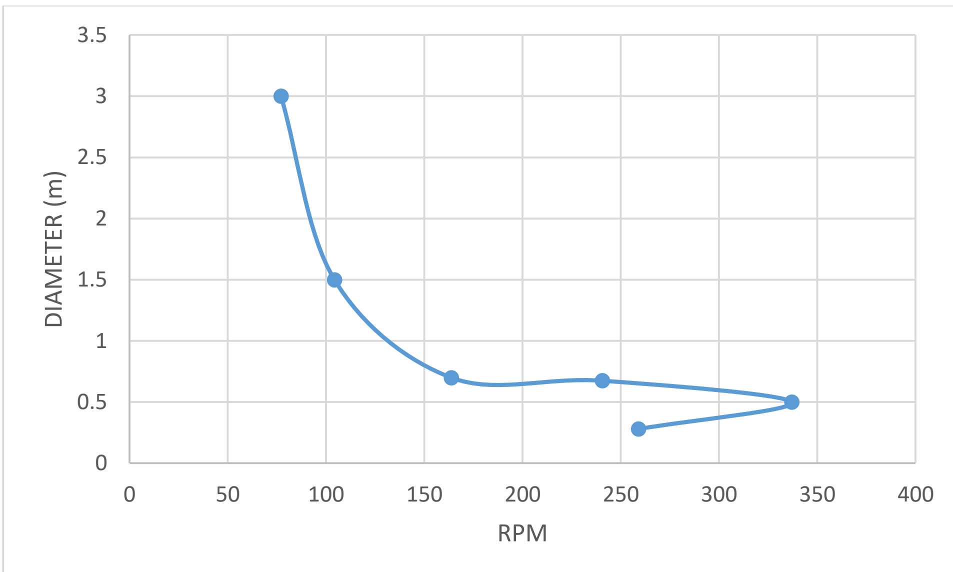

Fig4.6 Variation of Diameter with respect to Speed in rpm for selection study of horizontal axis turbine.

The correlation is developed between the diameter of turbine as a function of speed as given in equation 4.4.

Equation of Fitting Curve

Linear model Poly 4:

y=-1E-09x4+1E-06x3-0.0002x2+0.0024x+3.6159 4.4

4.3.3 Darrieus Straight Blade Turbine

Darrieus type rotors are lift devices, characterized by straight blades with an air-foil cross section. They have relatively high power output and low starting torque for given rotor weight. Darrieus turbine has two or three thin curved blades with air-foil cross-section and constant chord length. Both ends of the blades are attached to a vertical shaft [11]. When rotating, these air-foil blades provide a torque about the central shaft in response to a water stream. A Darrieus is a high speed, low torque machine suitable for generating alternating current (AC) electricity. Darrieus generally require manual push therefore some external power source to start turning as the starting torque is very low as shown in Fig 4.7.

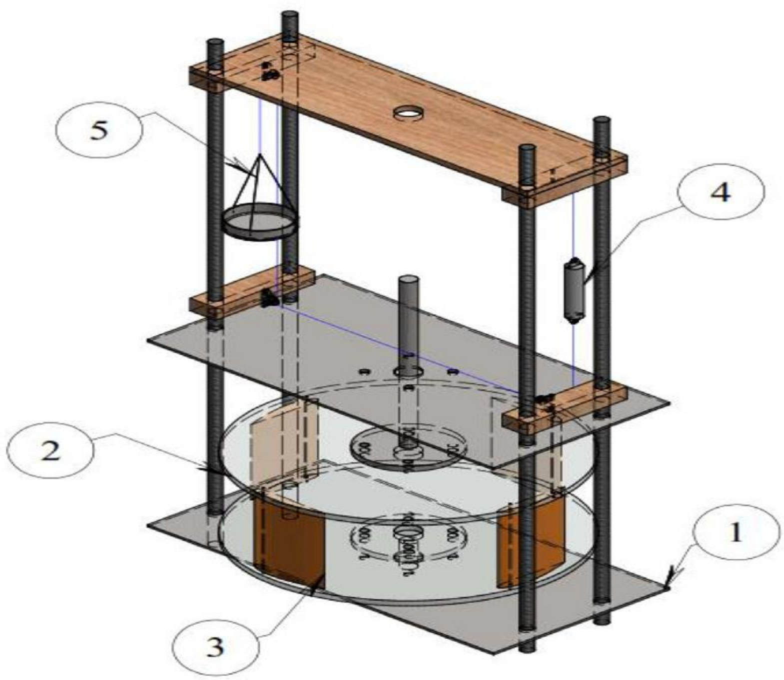

Fig 4.7 Experimental set up of Darrieus straight blade turbine [50]

(1) Rotor base plate (2) Rotor end plates (3) Rotor blade (4) Spring balance (5) Load Pan

It has high coefficient of power and simplicity in fabrication. It is capable to generate electricity in the range of 300W to 2 kW which would be useful in remote areas. Darrieus hydrokinetic turbine has the following advantages,

- Simple in design and easy to manufacture compared to conventional hydraulic turbines: It is very easy to install in river or canal water flow stream. Due to which it will be best suited for power production in remote locations.

- High coefficient of power compared to other hydrokinetic turbines like Savonius turbine: Owing to this property, it is best suited for continuous power generation for constant load applications.
- Water current has well defined flow direction. This eliminates use of yaw control and reduces complexity. This improves reliability and reduces maintenance.

Because of the above mentioned advantages, Darrieus turbine is suitable for the following applications,

- Small scale standalone hydraulic turbine that can be used to generate electrical power for household applications.
- By using hydro farm of Darrieus turbines, generated power can be delivered to the main grid.
- To operate water pumps, charging batteries, powering telecommunications and several other low power applications.

There are following data of Darrieus straight blade of different diameter with tip speed ratio, blockage ratio, Coefficient of performance, Cp maximum and velocity taken from different published paper as shown in Table 4.3.

Table 4.3: Data for Darrieus straight blade hydrokinetic turbine obtained from published papers

Diameter of turbine(m)	Number of blade	TSR range	TSR Opti mum	Velo-city range	Vel-ocity (m/s)	R P M	C_P range	C_P Max	Ref erence
0.15	3	0.39-.7	0.7	1-2.5	2.5	222.92	0.08-.37	0.37	33
0.22	3	0.4-1.6	0.8		2	138.96	0.04-.16	0.16	50
0.25	3	0.8-1.6	0.9		2	137.57	0-.16	0.16	50
0.32	3	0.8-1.1	0.9		2	107.48	0-.04	0.04	50
0.6	3	0.5-3.2	1.4	.5-1.5	1.5	66.87	0-0.3	0.3	35
0.9	3	1.25-2.3	1.5		1.3	41.40			36
1.2	3	0.9-2.4	1.6	.25-1.5	1.4	35.66	0.1-.35	0.35	36
1.6	3	1.5-3.25	2.25	1.1-1.4	1.4	37.61			24
2.2	3	1.8-3.4	2.5	1.5-1.9	1.9	41.25651	0-0.4	0.4	37

This plot diameter of turbine vs tip speed ratio for Darrieus straight blade hydrokinetic turbine and data are collected from published paper. Objective of this below curve is to determine a suitable range of diameter of Horizontal axis hydrokinetic turbine based on tip speed range and coefficient of performance of turbine**.**

It is clearly shown in the Fig 4.8, when the diameter of Darrieus straight blade horizontal turbine increases then TSR increases.

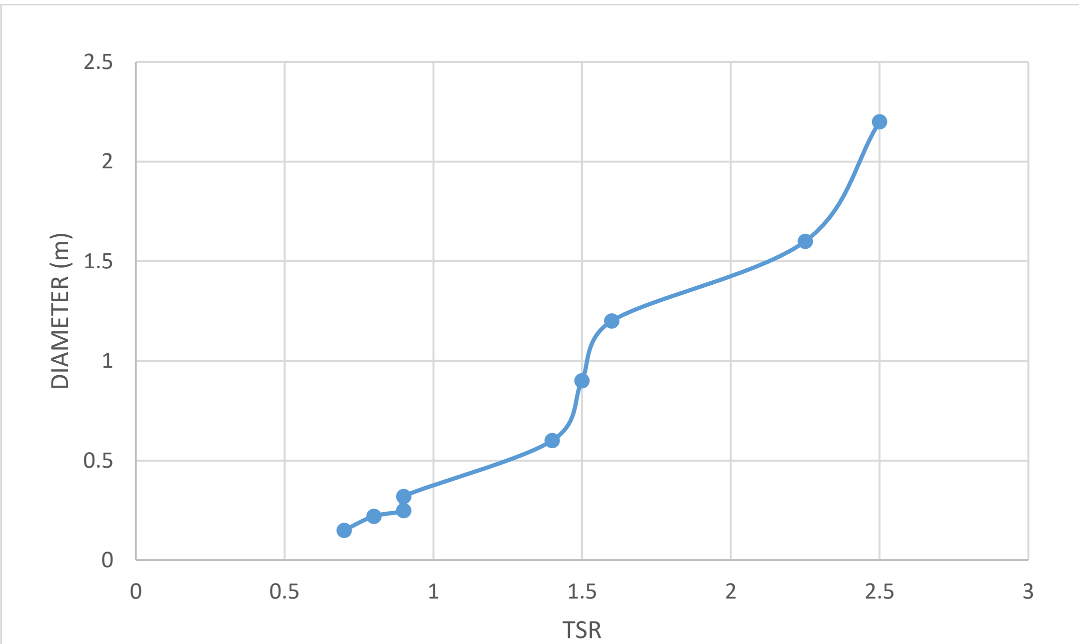

Fig 4.8 Variation of Diameter with respect to TSR for selection study of Darrieus straight blade turbine

The correlation is developed between the diameter of turbine and speed as given in equation 4.5.

Equation of curve

$$y = 0.1757x^2 + 0.536x - 0.3273 \quad (4.5)$$

Under the present study, the graph is plotted speed in rpm at x-axis and Diameter in meter at y- axis. It is clear that from above graph diameter of rotor increases, speed of turbine decreases upto certain limit after that diameter of turbine increases but speed is approximately constant. In above graph when diameter increases from 900 mm to2200 mm but speed value is not decreases, because of for large diameter of turbine speed of turbine attains minimum value for same stream velocity as shown in Fig 4.9.

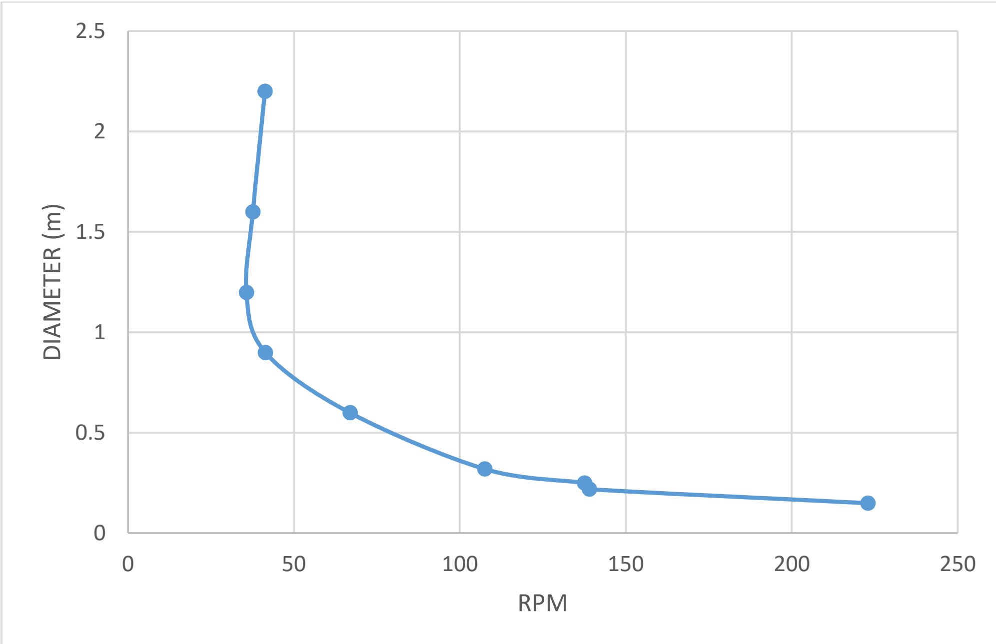

Fig 4.9 Variation of Diameter with respect to Speed in rpm for selection study of Darrieus straight blade turbine

The correlation is developed between the diameter of turbine and speed as given in equation 4.6.

Equation Of Curve

Linear model Poly 4:

$$y = -2E\text{-}08x^4 + 1E\text{-}05x^3 - 0.0023x^2 + 0.1606x - 1.9597 \qquad 4.6$$

4.3.4 Darries Helical Blade

The Darrieus turbine is a highly efficient and high r.p.m turbine. It is being used for power generation. However some practical implications are challenging the use of Darrieus hydrokinetic turbine, which are the use of steady angle of attack (AOA) of incoming fluid

The design parameters that in fluence the performance of a vertical-axis helical-bladed hydro turbine are its blade profile, solidity ratio (s), number of blades (n) and helix angleas shown in Fig 4.10. The blade profile selection is a vital parameter for achieving an improved hydrodynamic performance as it influences the performance due to alterations in the forces when subjected to an incoming fluid flow. Another crucial consideration while designing turbine is the optimum number of blades.

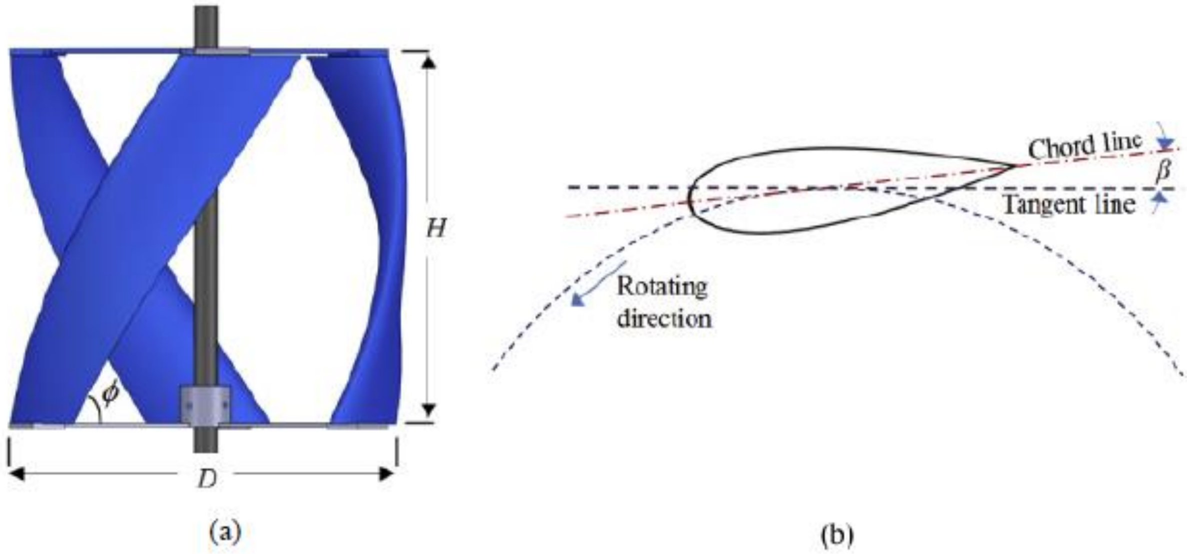

Fig4.10 Tested Darrieus helical blade turbine [38]

There are following data of Darrieus helical blade of different diameter with tip speed ratio, blockage ratio, Coefficient of performance, Cp maximum and velocity taken from different published paper in Table 4.4.

Table 4.4: Data for Darrieus helical blade hydrokinetic turbine obtained from published paper

Diameter of turbine(mm)	Number of blade	Immersion level	TSR range	TSR optimum	Speed (RPM)	Cp range	Cp maximum	Velocity (m/s)	Reference
300	3	60%	0.4-.85	0.5	27.70	.02-.08	0.08	0.87	38
		73%	0.5-.95	0.6	33.24	.07-.12	0.12		
		86%	.6-1.1	0.9	49.87	.07-.15	0.15		
		100%	.6-1.25	1	55.41	.07-.22	0.22		
340	3	60%	.45-.75	0.5	23.88	.02-.06	0.06	0.85	38
		73%	.55-.85	0.65	31.05	.045-.1	0.1		
		86%	.65-1.0	0.7	33.43	.03-.12	0.12		
		100%	.65-1.25	0.9	42.99	.08-.22	0.22		
370	3	60%	.5-.75	0.55	22.72	.02-.05	0.05	0.8	38
		73%	.5-.75	0.57	23.54	.02-.06	0.06		
		86%	.55-.9	0.6	24.78	.02-.08	0.08		
		100%	.6-1.15	0.8	33.05	.06-.16	0.16		
900	3	100%	1.6-3	2.0	84.92	0-0.25	0.25	2.0	40
1000	3	100%	0-3	2.25	94.58	0-0.25	0.25	2.2	42

Objective of curve is to determine a suitable range of diameter of Darrieus helical blade turbine based on tip speed ratio and coefficient of performance of turbine**.**

So finaly it is also observed that if larger diameter darrieus turbine operates at range of velocity from 1.4 m/s to 2.4 m/s then provides higher value of coefficient of performance compared to lower value diameter darrieus turbine as shown in Fig 4.11 and also shows in Nomogram curve.

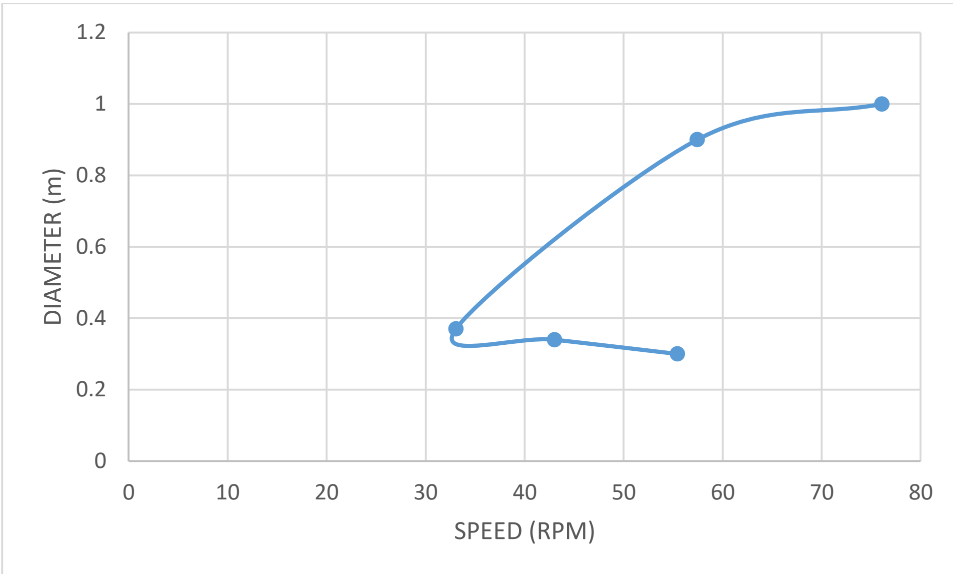

Fig 4.11 Variation of diameter with respect to speed in rpm for selection study of Darrieus helical blade turbine

The correlation is developed between the diameter of turbine and speed as given in equation 4.7.

Equation Of Curve

$$y = 0.0003x^2 - 0.0154x + 0.527 \quad (4.7)$$

Under the present study, performance of Darrieus hydrokinetic turbine is considered by using coefficient of power and tip speed ratio but for selection of turbines,Darrieus helical blade turbine of desired diameter operates the range of free speed velocity of 0.8 m/s to 2.2 m/s for maximum coefficient of performance. It is clearly seen from above figure 4.11 that initially diameter increases so speed decreases but after certain value ie speed 33 rpm and diameter 370 mm ,when diameter of rotor increases speed also increases because of high stream velocity for turbine of diameter of 900 mm and 1000 mm . Here drastically increase in value of free stream velocity from 0.8 at diameter of .37 m to 2.2 m/s at diameter of 1000 mm .Hence for larger free steam velocity large speed generator and large diameter turbine is useful for selection of turbine.

4.4 NOMOGRAM CHART FOR SELECTION OF HYDROKINETIC TURBINES

Using the data studied for diameter, speed and flow velocity, a nomogram has been developed .A nomogram is a chart often used to select a suitable turbine for a particular site. It shows design parameters for hydrokinetic turbine ie diameter of rotor and speed of turbine for different turbines in the same chart. The nomogram provides assistance in determining zone sizes for larger areas.

The Nomogram facilitates Selection of turbine and diameter of turbine if the velocity of flow and speed RPM of generator are known. This Nomogram is developed between the diameter in meter at Y- axis and speed in rpm of turbine at X-axis and the another variable is free stream velocity in meter per second at site. Free stream velocity is very useful parameter to select the hydrokinetic turbine for selection of turbine.

Different types of hydrokinetic turbines can be selected for given free stream velocity and speed in RPM of generator. Fig 4.12 shows the application range of various hydrokinetic turbines.

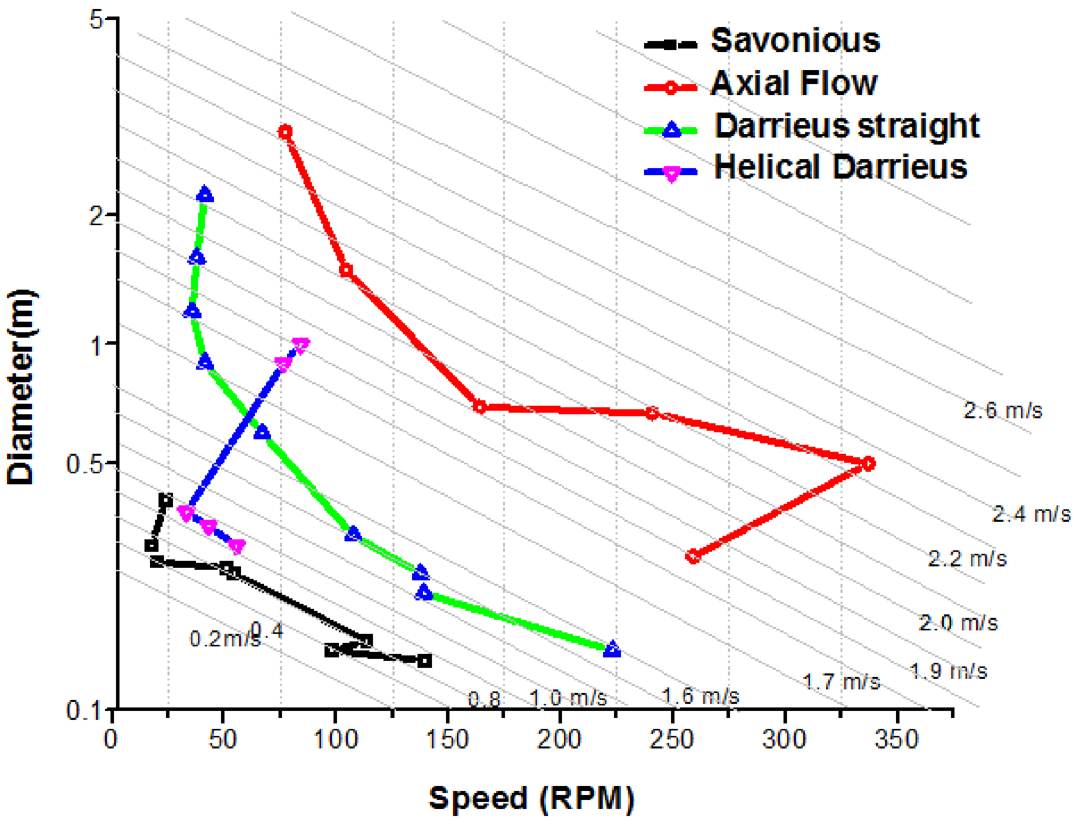

Fig 4.12 Variation of Diameter with respect to Speed in rpm for selection study of different types of hydrokinetic turbine

Steps involve for using Nomogram are given in a flow chart as shown in Fig 4.13.

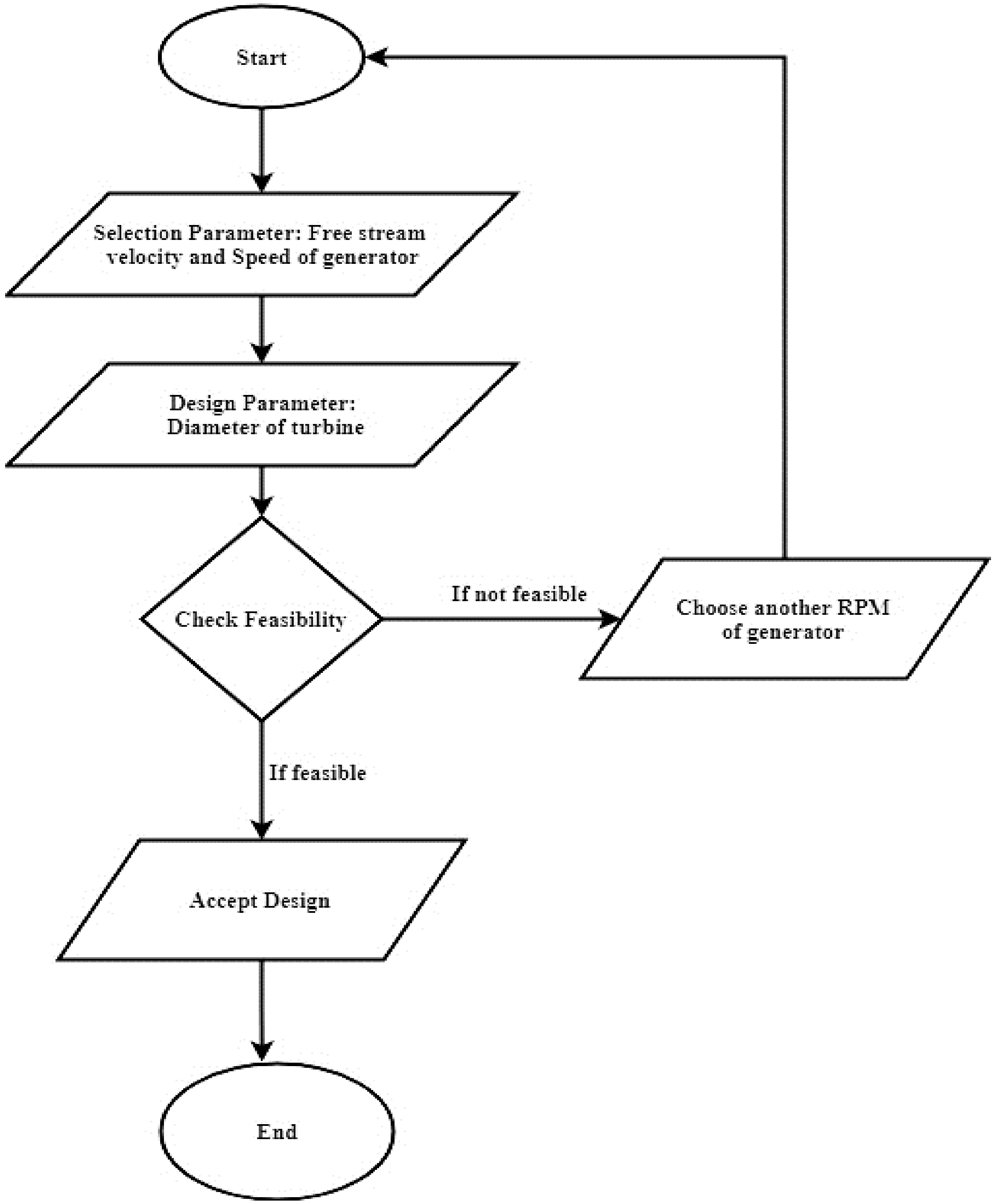

Fig 4.13 Flow Chart of Turbine for Selection of turbines

From the Fig 4.12 Nomogram, it is known that

i. Savonious turbine operates for velocity range of 0.4 to 1.2 m/s and speed of turbine range of 17 to 135 rpm.
ii. Darrieus straight blade turbine operating for velocity range of 0.46 to 2.0 m/s and speed of turbine range of 25 to 225 rpm.
iii. Darrieus helical blade turbine operating for velocity range of 0.8to 2.0 m/s and speed of turbine range of 33 to 75 rpm.
iv. Axial flow turbine operating for velocity range of 0.4 to 1.2 m/s and speed of turbine range of 17 to 135 rpm.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Under the present dissertation work, it is proposed to develop a procedure for selection of turbines of hydrokinetic turbine based on the working parameters and site condition parameters. The measurement of the efficiency of the developed turbines is the main concern for optimal designs. Under this paper, a literature review is carried and presented basically on efficiency measurement aspect for selection of turbine.

In this work, an attempt has been made also to develop a nomogram between diameter of turbine and speed in RPM for different types of hydrokinetic turbines. The results from this nomogram are used to select the suitable turbine for different range of Speed in RPM and compare the performance in terms of power coefficients with respect to various other affecting parameters. The conclusions of the present study drawn are as follows;

i. The suitable flow velocity for savonius is found to be 0.5 to 1.2 m/sfor maximum tip speed ratio of 1.2 and minimum tip speed ratio of 0.4 ,the turbine diameter lies between 140 mm and 400 mm respectively and correspond to for maximum speed of 137 rpm and minimum speed of 13 rpm, the turbine diameters are recommended as 160 mm and 300 mm respectively.

ii. In case of Horizontal axis turbine, for maximum tip speed ratio of 7 and minimum tip speed ratio of 1.86, the turbine diameter are 500 mm and 550 mm respectively and correspond to maximum speed 337 rpm and minimum speed 66 rpm, the turbine diameter is found to be as 500 mm and 3000 mm respectively.

iii. For Darrious straight blade turbine ,for maximum tip speed ratio of 2.5 and minimum tip speed ratio of 1.5 ,the turbine diameter are 600 mm and 900 mm respectively and for maximum speed 119 rpm and minimum speed 35 rpm, the turbine diameter of 600 mm and 1200 mm respectively.

iv. In case of Darrious helical blade turbine ,for maximum tip speed ratio of 1.0 and minimum tip speed ratio of 0.8 ,the turbine diameter are 300 mm and 370 mm respectively and correspond to maximum speed of 94 rpm and minimum speed of 33 rpm, the turbine diameters are recommended as 1000 mm and 370 mm respectively.

As the above discussion, various types of hydrokinetic turbines are studied and presented in this report. Based on the studies it is found that the cross flow turbine having straight bladed Darrieus turbine is more suitable for River application.

5.2 RECOMMENDATIONS

Based on present study, it is recommended that, further studies are required to investigate on the following areas and aspects of different types of hydrokinetic turbine;

i. There is a need to test the turbine at actual site for testing and more work can be carried out to analyse and investigate the performance of hydrokinetic turbine.

ii. Further research is required to carry out determine the turbulence parameters, and the effects of flow or vortex induced vibrations (VIV) and effect of cavitation effect.

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