# Micro hydropower turbines designs: A Review.

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**Abstract—** To provide electricity in off grid areas of the country, Pico-hydro power plants are very good option. Harnessing of energy from falling water,is theHydro power,such as water falling through steep mountain as a waterfall. The flowing water energy is converted into useful mechanical power by means of a water turbine. By using an alternator or a generator.the mechanical power from the turbine can be converted into electricit. Hydro power plant scheme are classified aspico, micro, mini & small having power generation capacity of less 5KW, 100kW, 1000KW, and 6000KW respectively. To supply power to a small group of users or communities,Pico hydro power plants may be used, where general electricity supply grid is not reachable. Generation of electricity through small natural water resources like waterfall or stream flow, can be used for small purposes at low cost. Actually this work utilizing natural water resource for such purpose started from 1853. This paper discusses review of work performed on generation of hydroelectric power by using various water turbine including already existing and also newly designed turbine. This paper is a comprehensive review of different types of water turbines developed by different researchers as per need.

**Index Terms:-** water turbine, review, small hydro turbine, turbine design, MHP.

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**Introduction:** Water is clean, cheap and environment friendly source of power generation which is important from ecological point of view.[1] Hydropower is utilized from last hundreds of years which is resourceful and consistent source of renewable energy. The scope of project work is to design and develop small size turbine concept to utilize the natural resource of energy in remote areas where it is not possible to construct power transmission line for providing electrification. A total of 32,227 villages of India are until now to be provided with electricity access, as per report on 31st August 2013. As per the 2001 census, as on 31st August 2013, a total of 561505 villages were electrified, out of a total of 593,732 colonized villages [2]. For hydropower development there is significant potential in the country. From such plants at more than 15,000 MW, power can be generated in India as per the Ministry of New and Renewable Energy (MNRE). The 11th Five Year Plan completed its term in March 2012. For improving the overall energy picture of the countryside particularly in remote and unreachable areas, mini, micro, and pico hydropower projects can play a significant role. As per ministry's plan at least half of the hydro potential of the country is harnessed upto the further ten years and that will be the installed capacity of small hydro facilities, it should be about 7,000 MW at the end of the 2017. For the next (12th) Five Year Plan period, MNRE is targeting a capacity n of 30,000 MW power generation from different renewable energy sources

An cumulative capacity of 3,632 MW had been installed in India, by announcing a policy in 24 states to invite private sector bodies to set up projects, by means of 967 small hydro projects, by the end of April 2013. An additional thing is that , 281 small hydro projects with a capacity of 1,061 MW are under progress.

For the Small Hydro Power (SHP) schemes, INR1.6 billion of grant was released, from 2012 to 2013. The largest amounts going to states such as Arunachal Pradesh, Himachal Pradesh, Jammu & Kashmir and Uttarakhand. As expected, most of the hydro-potential of power generation is from river-based projects in Himalayan states, and on irrigation canals in other states. To focus mainly on SHP program, and to minimise the cost of equipment, increase reliability and arrange projects in areas that give the maximum advantage in terms of capacity utilization.

According to MNRE, its SHP program is now essentially being driven by private investment, and it finds that projects are usually economically feasible. The private sector taking lot of interest in investing in SHP projects. Number of peoples studying on the installation of SHP in India. From the overall study they closing that there is“assured future of small hydropower in India."[3].

1. **Motivation in designing different turbine:** In 1976 Mohammd Durali [4], designed the turbine for farmers who having little technical knowledge, so completed structure design is avoided. These turbines are designed with simple structure so that they can be used in a period of years when plenty of water is available. Design should be cheap so that machine can be built locally in each farming area as well as can be manufactured in simple workshop having enough facilities. In July-1999, Alastair Gill, ESD, Neston Paul Mosley, [5] To help rural people to improve their financial condition and get better life-style, micro-hydro power designed, which has proved as a very successful tool. In a village areas which are away from the grid, to reduce the hard work of food processing and to offer a ways of generating electric power, MHP provides required energy. In Dec’ 2007 Miyoshi Nakijama, Shishnu University, Japan,[6] developed environmentally friendly nano hydraulic

turbine, in which two bucket savonius type turbine is constructed and tested in water channel with an optimal installation condition. This turbine can be used efficiently as a nano hydro turbine & dispersed power system. These types of turbines are suitable for rivers or canals in which net head is not sufficient while the flow-rate is enough. In July 2009 Toshihiko Ikedo, Jio, Kenji-Shishnu University Japan, [7]focused on development of environmentally friendly nano-hydraulic turbine using waterfalls. Sebastian Hermann,[8] Battery charging potential using small hydropower resources in rural areas with respect to its efficient and technical feasibility were investigated and explored. In April 2012, Bryn Patrick HO-Yan,[9] Pico hydropower (≥5KW) has been identified as promising means for rural electrification.

2. **Hydro Power Basics:** In this section basic fundamentals terminology regarding design of MHP turbine is discussed. Further in the next section design of various turbine will be discussed.

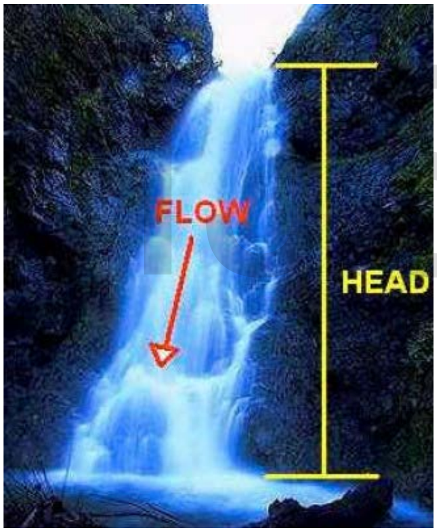

**Fig1:** Waterfall showing its flow and head measured .(Source: Mini-hydro power plant)

**Head and Flow:** "Head", the vertical fall of the water, necessary for generation of hydropower. A water discharge **Q**, and a net Head $\mathbf{H_n}$, two quantities are required. To keeps the machinery smaller, it is better to have more head than more flow,

**The Gross Head:** ($H_g$) Vertical fall of water, from the top level to the bottom level, is the gross head.

**Flow Rate (Q)** in, is the volume of water passing through river per second, measured in $m^3$/sec.

**Power and Energy:** Energy converted per second, is nothing but power, measured in watts (where, 1000 watts=1 kilowatt). Initially stored energy of the water is converted to equal amount of kinetic energy, in a hydro power plant. To calculate its P.E., the height of the water is utilized and utilized to speed up the water at the entrance of the turbine by balancing both energies of water.

Potential energy of water $E_{pe} = m*g*Z$ (Z is nothing but H) Equation(1)

Kinetic energy of water $E_{ke} = ½ * m *c^2$ Equation (2)

For any hydro system's power is given by the general formula

$\mathbf{P} = \eta_h \rho \mathbf{gQH}$ Equation (3)

**Where,**

- m = Water mass (kg),
- **g**= gravitational acceleration. (9.81 $m/s^2$),
- **H** = pressure head of water. (m).
- **c**= water jet velocity (m/s), Thus, $c = \sqrt{(2gH)}$
- **P** =power (mechanical) produced (Watts),
- $\eta_h$= hydraulic efficiency.
- ρ = water density (1000 $kg/m^3$),
- **Q** = volume of water passing through the turbine ($m^3/s$),
- Hydraulic efficiencies of best turbines vary 80 to 90%, which reduce with size. Micro-hydro schemes having power generation capacity <100KW are 0.6 to 0.8.

**Capacity Factor:** The 'Capacity factor' of turbine is expressed as, how reliably a turbine is working.

Capacity factor (%) =Energy generated/year (kWh/year) / {Installed capacity (kW) x 8760 hours/year}

**Energy Output:** Work done in a certain time,is the'**Energy**', measured in Joules.

Energy (kWh/year) = **P** (kW) × **CF** × 8760. [10]. Equation (4)

**Turbine selection criteria:** An appropriate turbine Selection mostly depends on the available water head and to a less extent on the available flow rate. [12]

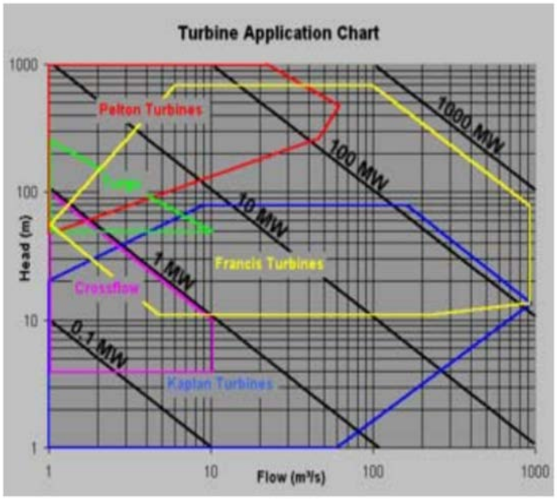

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**Fig:2** Source: Micro Hydro Power, Resource Assessment Handbook Prepared for APCTT (pg.no26)

Above turbine application chart is useful for selection of turbine to be design for power generation, as per availability of head and water discharge. Power generation ranges of different turbines is shown on a chart in MWatt.

## 3. Design Work:

### 3.1 Design A

**(Reaction turbine)**[31]In April 2011, Sir Robert Simpson & Arthur Williams, For this design procedure they used the following equation:

Specific speed $=n_q = \frac{N\sqrt{Q}}{H^{0.75}}$

Equation(5)

Where, $N$ is in (rpm), Q in( $m^3$/s) and H in (m), all above parameters were founded by standard method available, and calculated'$n_q$' . From the range of specific speed type of turbine to be designed is decided. If'$n_q$' is correct, from 'sizing sheet' for diameter for hub and tip of runner is choosen. For further calculation actual size & no. of blades are are used as input. From this standard runner sheet gives flow velocities. For this if $v_{w2}$was correct, runner sheet provides blade design data. Further if possible to manufacture then standard spiral sheet provides scroll dimensions. If difficulties to manufacture then again change values blade parameters and also hub tip ratio.

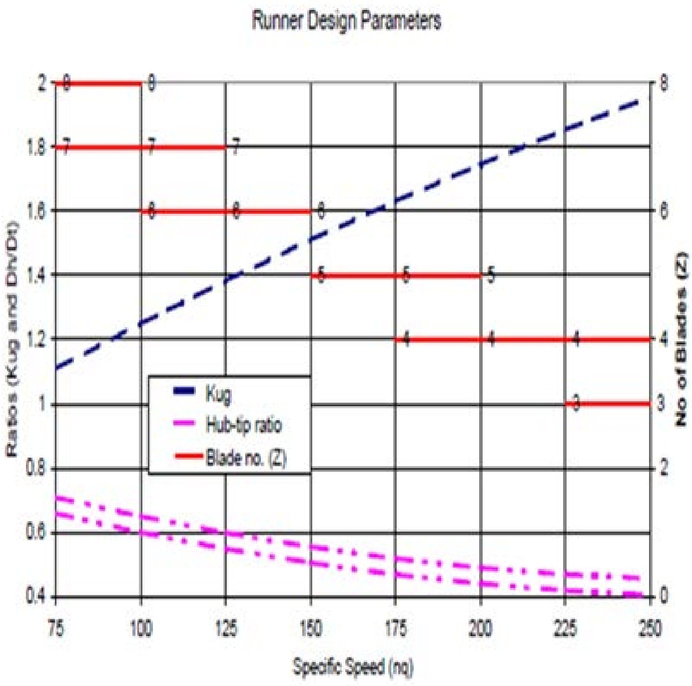


**Fig 3:** Design parameters for 'sizing' sheet.

$$k_{ug} = \frac{r_{tip}\times\omega}{\sqrt{2gH}}$$

Equation (6)

$r_{tip}$= D/2 , is $r_{tip}$ the blade tip radius, and ω in in rad/s, is the angular velocity of the turbine runner, i.e. ω = 2$\pi$N/60. In the spread sheet the specific speed($k_{ug}$ )is calculated, as shown in above graph. In "Sizing" sheet.there are two other parameters which are input by the designer, as shown in graph. Those are the the number of runner blades (Z), and diameter ratio of runner hub:tip The values on the graph are for guidance. The values of the number of blades are customized because ,it is better to have fewer blades on the runnerfor small turbines.[12]. This is *pico hydro* turbine design, range of power generated is less than 5Kw.

[14] To obtain the runner blade shape and characteristics CFD-based design method was used. With the provided parameters for a specific power plant, the design of the runner blade starts. Those parameters areQ (Discharge or flow rate), H (Head) and Ns (Specific Speed). Simple runner angles of leading and trailing edges are determined, by using in-house codes. By using a CFD software for meshing and for simulations using the grid generation module of the same software, runner blade shape is designed. CFD with k-ε turbulence model was used to simulate the geometric design

.By changing the runner shape the procedure is repeated, to obtain accurate results. The CAD model of the blades is generated when the designed shape with the necessary conditions of head, efficiency, outlet flow angle (alpha) and minimum pressure value for cavitation free operation. As a part of the developed runner design methodology, mechanical analysis of the design was also performed. For the parametric, CFD aided design and manufacturing of hydro turbine runners, a collaborative design methodology was developed.The design and manufacturing methodology for ***Francis water turbine and its runner*** is developed by using a specific power plant.

## For runner design,

From Fig 4 of flow velocities,using following Euler's equation:

$$gn_hH = u_1v_{w1} - u_2v_{w2}$$
Equation (7)

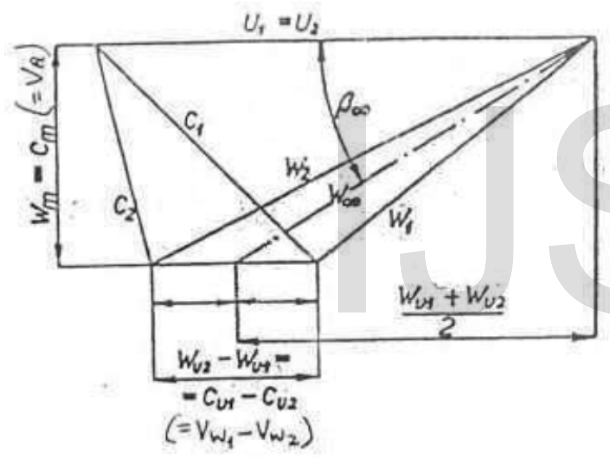


**Fig 4:** Diagram of flow velocities, with w2 = u

Where, $u$= the runner peripheral speed (1 at entrance and 2 at exit) and

$v_w$= the water velocity tangential component.

For an axial flow turbine, $u_1$=$u_2$.

The axial flow velocity through the runner or rotor is calculated from:

$$v_a = \frac{Q}{\pi {r_t}^2 - r_{h^2}} = \frac{4Q}{\pi D_{t^2 - D_{h^2}}}$$
Equation (8)

Where, $r_t$= the runner outside radius (tip radius), and

$r_h$= the runner blade inside edgeradius (hub radius).The value of $v_{w1}$ as a variable for the designer to choose, is used as input. In some cases – e.g. For an existing casingwhere a new runner is being designedis already set by the scroll design. But by changing the values of $v_{w2}$ and $w_2$normally it can be adjusted. An initial guess for $v_{w1}$is given in the spreadsheet, based on the Euler Equation and assuming that $v_{w2}$ is positive and is 10% of $v_{w1}$.(shown in above Fig 4)

$$v_{w2} = v_{w1} - \frac{gn_hH}{u}$$
Equation (9)

$$w_{1^2} = u - v_{w1^2} + v_{a^2;\ w_{2^2}} = u - v_{w2^2} + v_{a^2}$$
Equation (10)

## 4.2 Design (B):

[15] Bilal Nasir,put some design considerations in his paper,

a). Discharge data organization is nothing but 'Flow duration curve'. By using the FDC, the river or stream, highest flow capacity of the turbine can be determined.

b). Flow rate measurement, Measuring the cross sectional area ($Ar$):

$$A_r = \frac{a+b}{2} \times \frac{h_1+h_2+h_3+\cdots.h_k}{k}(\mathrm{m}^2)$$
Equation (11)

Where,

\a = Top river-width ($m$), b = Bottom river-width(m)

$\frac{h_1+h_2+h_3+\cdots.h_k}{k}$ = average height of water in the river or stream ($m$).
Equation (12)

c). The velocity-measurement ($Vr$):

Surface speed is, $V_{rs} = \frac{L}{t}$ $(m/s)$
Equation (13)

$V_r = 0.75 \times V_{rs\ (m/s)}$
Equation (14)

d). Flow rate/discharge of river or of stream can be calculated as:-

$Q = A_r \times V_r$ $(m^3/s)$
Equation (15)

d). Gates and valves in MHP: For the intake small and micro-hydro systems, a descending gates of steel , plastic or timber , and cast iron, are suited

e). Meaning of Vorticity: Uneven flow form of water introduces air into the stream with bad results on the turbine and draw debris at the entrance is nothing but Vorticity f).Meaning of trash rack, to avoid the debris to enter into the entrance. The coefficient (*Ktr) of* trash rack depends on the block shape and it is changeable between 0.8 to 2.4.

The minimum value of submersion (*hs*) is given by:

$h_s \geq D_h \times [1 + 2.3 \frac{V_{en}}{\sqrt{g \times D_h}}]$
Equation (16)

where, $D_{h=}$ diameter of thehydraulic downstream channel (*m*).

$V_{en}$= velocity at entrance (*m/s*).

*g* = Gravitational acceleration constant (9.8 *m/s2*)

The speed (N in r.p.m) of turbine can be calculated as:

$N = \frac{60 \times w}{2\pi}$ (rpm),
Equation (17)

*N*= speed of turbine

The specific speed is defined as:

$N_s = \frac{N \times \sqrt{P_t}}{{H_n}^{5/4}}$ (rpm)
Equation (18)

Where,

*Pt*= power of turbine in (*Kw*).

h). Turbine power$P_t = \rho \times g \times H_n \times Q \times n_t$ (watt)
Equation (3)

Thus, by Matlab Simulink design steps of MHP plant was applied after introducing the site measurement and calculations as input data to the machine control unit- program through which all above parameters are determined. Following designs for different turbine was given,

**4.2.1 Design of pelton turbine:** The sizes of the Pelton turbine can be estimated from the following equations: if the runner speed ($N_r$), the net head and water flow rate (*Q*) are known,

$D_1 = 40.8 \times \frac{\sqrt{H_n}}{N}$ Buckets center line describing diameter of circle (m) Equation (19)

$B_2 = 1.68 \times \sqrt{\frac{Q}{K}} \times \frac{1}{\sqrt{H_n}}$width of bucket ( m). Equation (20)

Where, *K*= number of nozzles.

$D_e = 1.178 \times \sqrt{\frac{Q}{K}} \times \frac{1}{\sqrt{H_n \times g}}$diameter of nozzle (m). Equation (21)

$D_j = 0.54\sqrt{Q}/\sqrt{H_n}$diameter of jet ( m).
Equation (22)

$V_{jet} = 0.97 \times \sqrt{2} \times g \times H_n$velocity of jet (*m/s*). Equation (23)

The ratio *D1/B2* must be >2.7 If the case is other than this, fresh calculations with additional no of nozzle has to be carried out. For the same power of Pelton turbine, if the turbine is Turgo, specific speed is double anddiameter is halfedof the Pelton.

**4.2.2.Design of Francis turbine:** A broad range of specific speed from 50(low head) to 350(high head) is covered . the major sizes evaluated as :

$D_3 = 84.5(0.31 + 2.49 \frac{N_s}{995}) \frac{\sqrt{H_n}}{N}$ diameter in (m)
Equation (24)

$D_1 = (0.4 + \frac{94.5}{N_s}) \times D_3$ Runner inlet diameter in (m)
Equation (25)

$D_2 = \frac{D_3}{0.96 + 3.8 \times 10^{-4} \times N_s}$Runner inlet diameter in (m)
Equation (26)

If, $N_s < 163\ then D_1 = D_2$

**4.2.3 Design for Kaplan turbine:** $D_e = 84.5(0.79 + 1.6 \times 10^{-3} N_{s)}) \frac{\sqrt{H_n}}{N}$Exit(outer) diameter of runner in (m)Equation(27)

$D_i = (0.25 + \frac{94.5}{N_s}) \times D_e$ Hub (inlet) diameter of runner in (m)
Equation(28)

**4.2.4 Design for cross flow turbine:** $D_r = \frac{40\sqrt{H_n}}{N}$ Diameter ofrunnerin (m) Equation (29)

$L_r = \frac{0.81 \times Q}{D_r \sqrt{H_n}}$ length of runner in (m)
Equation(30)

$t_j = \frac{0.233 * Q}{L_r \sqrt{H_n}}$ Jet thickness orwidth nozzle in (m)
Equation (31)

Thus, micro hydro power plant turbine design –*pelton, francis, Kaplan and cross flow turbine* was explained.

[16] Finnemore, E.J. and Franzini, explained essentials of hydraulic turbine design and analysis, wherein,

specific speed =$N_s = \frac{n_e \sqrt{gpm}}{h^{3/4}}$
Equation(32)

Where, $n_e$ is the rpm (optimum operating efficiency), *h* is in feet.

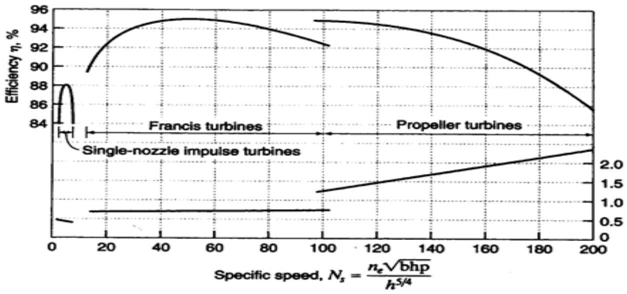


**Fig 5 :** maximum turbine efficiency and typical values Φc as a function of specific speed.[ 2]

### a. Nozzle Design:

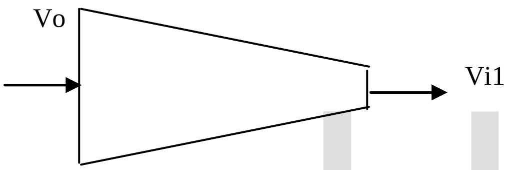


**Fig: 6** Nozzle Design[2]

$V_{i1}$(the ideal exit velocity),is determined From the following equation:

$$\frac{P_0}{\gamma}+\frac{V_0^2}{2g}+Z_0=\frac{P_1}{\lambda}+\frac{V_{i1}^2}{2g}+Z_1$$

Equation (33)

Velocity at entrance is the product of ideal velocity and a velocity coefficient, $V_1 = C_v V_{i1}$

Conservation of mass directs to: $Q = C_d A_1 V_1$

Equation (34)

Where: $C_d = C_c C_v$

**b. Nozzle Dimensions:** The criteria for diameter of nozzle should be 20% greater than the calculated diameter of the jet at discharge.

### c. Rotational Velocity:

| Head (ft) | Specific Speed ($n_s$) |
|---|---|
| 1000 | 5.0 – 5.5 |
| 2000 | 4.0 – 5.0 |

$$n_s = \frac{n\sqrt{W_{shaft}}}{H^{5/4}}$$

Equation (35)

Where: $n$ = rpm; $\dot{W}_{shaft}$ = shaft horsepower; $H$ = turbine head, (feet).

Rotational velocity= $n = \frac{120f}{p}$, Where: $f$ = frequency (60 cycles/ sec),$p$ = no of poles.

**d. Runner Diameter:** ($D_p$): $D_p = \frac{1840\phi\sqrt{H}}{n}$

Equation(36)

**e. Absolute Bucket Entering Velocity:** $V_{1,ideal} = 2U$

Equation(37)

Where: $U$ = peripheral velocity of a point on the pitch dia. of the bucket.

**f. Bucket Shape and Dimensions:** The shape of bucket is semi-ellipsoidal on both "splitter", a sharp-edge of bucket divides the flow, into one-half, going to both side.

Estimation of bucketsizeas follows:

Width - B = 3d Depth - D = 0.85d Length -L = 2.6d

Where: $d$=diameter of jet

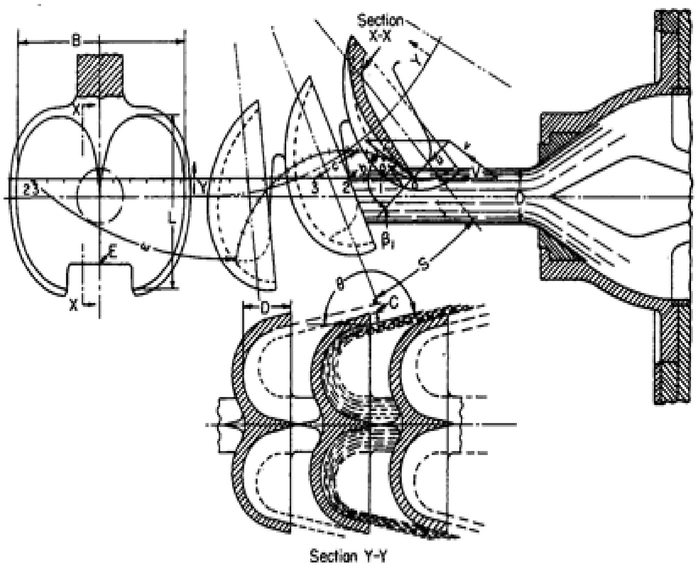


**Fig7:** Impulse turbine bucket diagram.[ 2]

Thus, author explained complete design procedure of ***pelton turbine*** in his book.

[17][18] In this paper the optimal selection of hydro turbines for hydroelectric projects is reviewed. In this section turbine selection is the first phase,can become a guideline for the developers in selection of hydro turbine for available operating conditions.

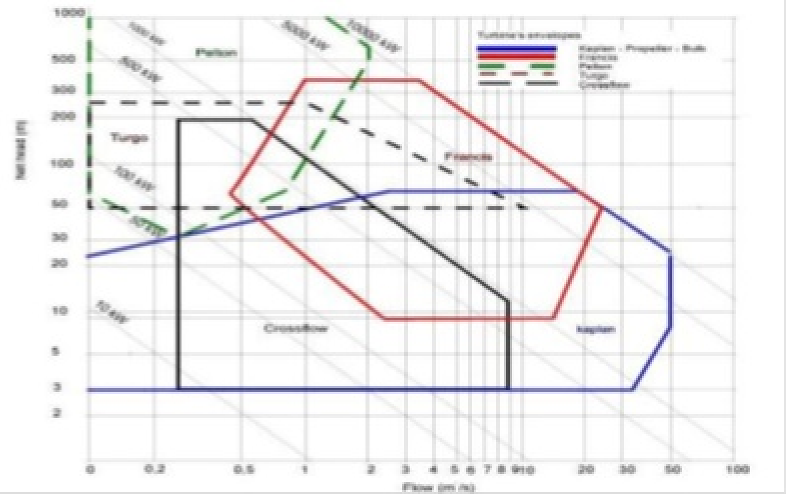


**Fig 8**: turbine selection chart based on head and flowrate.[17

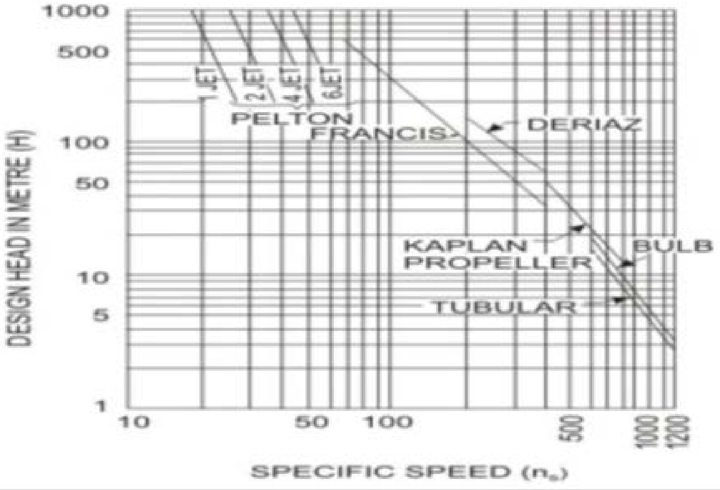


**Fig 9:** Chart for determining the selection of turbine.[17]

Above Fig 8 & 9 shows chart for optimalselection of turbine, based of head and flowrate and second chart is based on availability of head and specific speed.

**4.3 Design (C):** [20] In this section author Flasp-Alhler given design procedure of Kaplan turbine,

**a. Power:** The runner power is determined as below:

$P = Q.H.\eta_h .\rho .g$ [W]

Equation(3)

The terms in equation are defined above.

By knowing head, discharge and assuming efficiency, power can be calculated.

**b. Speed of the turbine:**

Specific speed= $n_{QE} = \frac{n\times\sqrt{Q}}{E^{3/4}}$,

Equation (38)

Where:

E=Machine specific hydraulic energy [J/kg]

n =The turbine rational speed [s-1]

A machine specific hydraulic energy can be proven as below:

$E = H_n \times g$ [J/kg]

Equation (39)

Where, $H_n$ = net head of flow [m]

$H_n = H \times g$[m]

Equation(40)

For Kaplan turbines correlation between the specific speed and the net head is given by:

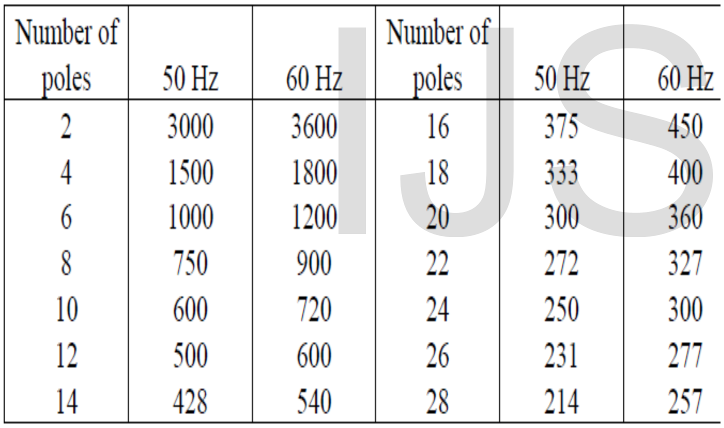
$$n_{QE} = \frac{2.294}{H_n{}^{0.486}} \qquad [-]$$

Equation (41)

As, the rational speed is unknown, the specific speed can be calculated with the above formula. Hence, a resulting specific speed can be calculated.

**c. Rational speed:** The rational speed can be calculated by putting equation (39) in equation (38). To obtain rational speed of the turbine, the resulting equation has to be re-arranged . This value of the rational speed is optimal because it is synchronous to the generator speed. Thus, the turbine can be directly coupled to following.

**Table1:** Generator synchronization speed/1/



| Number of poles | 50 Hz | 60 Hz | Number of poles | 50 Hz | 60 Hz |
|---|---|---|---|---|---|
| 2 | 3000 | 3600 | 16 | 375 | 450 |
| 4 | 1500 | 1800 | 18 | 333 | 400 |
| 6 | 1000 | 1200 | 20 | 300 | 360 |
| 8 | 750 | 900 | 22 | 272 | 327 |
| 10 | 600 | 720 | 24 | 250 | 300 |
| 12 | 500 | 600 | 26 | 231 | 277 |
| 14 | 428 | 540 | 28 | 214 | 257 |

## d. Diameter of runner :

Diameter of Runner ‘De’ can be determined as below:

$$D_e = 84.5 \times (0.79 + 1.602 \times n_{QE}) \times \frac{\sqrt{H_n}}{60 \times n} \qquad \text{(m)}$$

Equation (42)

## e. Diameter of Hub:

Diameter of hub ‘Di’ can be determined as below:

$$D_i = [0.25 + \frac{0.0951}{n_{QE}}] \times D_o$$

Equation (43)

Thus, this is basic design procedure for Kaplan turbine. Also design of blade and forces acting on blade are explained.

## 5.Economy of micro hydro power plants:[19]

**5.1 Economic evolution:** The capital cost was minimized and revenue from energy produced was maximized. The intake, penstock and discharge pipe work at water treatment works may already exists which reduces the capital cost of the scheme. To maximize the returns from energy cells, the plants must be operated at maximum capacity for the longest possible periods of time.

### 5.2 Actions to reduce the costs:

1. To save civil-work cost, building cost, hydro-Mechanical equipments cost, control system duplication, electric wiring etc. the number of components should be limited to 2-3.

2 Simpler edition of water level controllers to be used, rather than going for complete Kaplan turbine, semi Kaplan where guide blades are unchanging.

3. Civil engineering cost can be minimized, by minimizing the sizes of Power house, control panels, instrumentation panels plan can be simplified.

4. To make the scheme economical, sizing with subsystems should be carefully decided.

5. Synchronous generators with associated subsystems, are more costlier than Induction Generator

6. With objective of reducing cost standardization of Hydraulic turbine is important. Turbines can be standardized by simple design of parts and keeping its sizes standard, which reduces the production cost and time of delivery.

7. Standardizing the Hydro-Mechanical equipments should continue , by manufacturers.

8. Implementation of electronic load controller devices and removal of guide vanes may reduce the cost.

9. In irrigation system low head falls harnessing is wanted by standardize design.

10. Particular funding and abundant term loan is given, to explore MHP generation which will be highly inexpensive for countryside industry and remote areas.

In this two plants one is dam toe and second is canal based are studied in M.P., of which dam toe plant is more beneficial in terms of returns of revenue. Though, the Cost/ KW is high as compared to Large Hydro Projects and Micro/Pico Hydro Plant supplies power to very limited locality, a villagers can have their own micro Hydro Power Plant (HPP). Thus if energy of canal drops is tapped effectively, the small remote villages can become self reliant in power. Micro hydro power is most cost effective renewable energy approach than solar or wind energy, as long as water is flowing.[19]

6. **Conclusion:** This paper focuses on review of different designs of micro hydro turbines. Also advanced technologies like CFD and ansys, Matlab-

simulink used for analysis and design the turbine parts by linking the finalized data to manufacture the prototype in 3D software. Economy of turbine is explained.

7. **ACKNOWLEDGMENT:** I am very thankful to Prof. Dr. P.S.Pingle who is my thesis guide, he helped me in all ways from strarting to the submission of work.

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