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Development of prototype turbine model for ultra-low head hydro power potential in Western Maharashtra

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Abstract: *Clean source of energy is playing very vital role in today's eco-friendly environment. Potential energy available with water can be converted into useful work by maintaining the purpose of clean environment. Hydro-power plant utilises the energy of water and can produce equivalent mechanical output. Hydro-electric power plants are much more reliable and efficient as a renewable and clean source than the fossil fuel power plants. The rivers in Western Maharashtra region flows from Sahyadri mountain towards Deccan platue with steady gradient. In recent years, the environmental impacts are becoming difficult for developers to build new dams because of opposition from environmentalists and people living on the land to be flooded. Therefore the need has arisen to go for the small scale hydro power plants in the range of mini (few MW) and micro hydro (kW) power plants. This paper discusses the conceptual design and development of a micro hydro power plant. The developed model can be used at sites having head range of 0.5 to to 6 m. The required information was collected from meteorological department and irrigation department of Kolhapur division of Government of Maharashtra, India.*

Keywords: *K.T. weir, Propeller turbine, Sahyadri Mountain, Ultra-low head hydro plant, WesternMaharashtra*

I. Introduction

The power generating capacity in Western Maharashtra from small and mini hydro is currently 1,100 MW (approx.) and is growing at rate of approximately 150 MW per year whereas 3300 MW of capacity is expected to be generated in 10 years. Most of this production will be from government power production, provincial/municipal utilities, and remote communities.

For the last twenty years, provincial and or municipal utilities, and remote communities have been increasingly interested in developing small hydro, generally with plant capacities less than 5 MW. Most of these small hydro plants serve as decentralized power, connected to local grids. Total annual installation of small hydro plants in Maharashtra increased from a capacity of 10 MW/year in mid-eighties to approximately 20 MW/year for the last few years.

There is significant availability of potential in small and medium hydro plants in Western Maharashtra. A large number of these sites are called as ultra-low-head or run-of-river, which do not require large reservoirs or dams, run on a special type of irrigation weir called Kolhapur Type Weir (K.T.Weir). Most of these hydro sites serve as decentralized power stations. The power produced from these plants can be utilised for drinking water supply schemes, to help keep the rural hospital running normally, to lit up the street lights at night time. [1, 2]

However, the further development of micro to small hydro will largely rely on efficient and lower up-front costs involved in the emerging technology which can prove a cost effective solution village panchayat and Samity. While world-wide High head hydro potential is vast (thousands of suitable existing dams), the development of this potential is very low due to its high development cost, particularly for the related civil works which represent 40-50% of the total development costs of any given project. [3]

This paper presents a prototype model of ultra-low head hydro power turbine, designed specifically for very low head sites (1.4 to 3 meters net head) in Western Maharashtra region. The objectives of the design of the ultra-low head hydro power turbine is to develop a unit that will require very few civil work, will be easy to install and will offer a high degree of reliability at a reasonable cost per installed kW.

II. Methodology

1) The first stage of the study is to recognise the principles of extracting power from a water source. This continued with the investigation into an understanding of the current technology, identifying the sites, finding the literature and the components required to complete a hydro system (includes the study of various types of turbine and mechanical plant) [3]
2) Several visits to the proposed sites were made, and the sites were photographed and surveyed with the help of Survey maps, to gain an understanding of the lay of the land.(Fig. 1)
3) As there is no monitoring equipment on the waterway historical flow rates, rainfall data from the

Meteorological Office, weather station nearby was used in conjunction with the Survey maps to calculate the volumetric flow rates for the site.

4) The data of water discharge from the Dams is collected from the irrigation department office at district level, as the control is purely in the hands of district collectors.
5) Further an enhanced model of simple reaction water turbine was developed and manufactured for optimum turbine sizing of ultra-low head. [4, 8]
6) After the prototype building, attempts were made to improve the turbine performance by minor or major design modification. [6,7,8,9]

Figure 1 K.T Weir at K// Tarale , Tal: Radhanagari, Dist: Kolhapur.(site for data collection and conducting the trials)

Specification of selected site:

Continuous flow of water throughout the year as it is located very near to Dhudhaganga Tunnel &provides a flow rate of 43 m^3/sec. The difference between upstream and downstream is near about 3 m.

III. Calculation Of The Main Characteristics

The main characteristic is the data on which the design of the runner is based. To calculate, for instance, the forces on the blade or to determine the dimensions of the adaptation mechanism the characteristics of the turbine are needed.

In figure 2, a sketch of a propeller turbine is given. On this sketch, those heads and points which play a significant role in this paper are marked.

3.1) Power

The power of the runner can be calculated with the following equation:

$$P = Q*H*\eta_h * g * \rho \text{ [W]} \quad (1)$$

Where: Q-discharge [m^3/s], H-gross head [m], η_h-hydraulic efficiency, ρ-water density [kg/m3], g-acceleration of gravity [m/s^2]

The site where the experimental rig of the turbine is built, provides a maximum gross head of 0.75 m. An efficiency of 0.8 can be assumed for a propeller turbine. Taking a discharge of 0.015 m^3/sec, the power of the runner is 70.49 W or 0.0704 kW

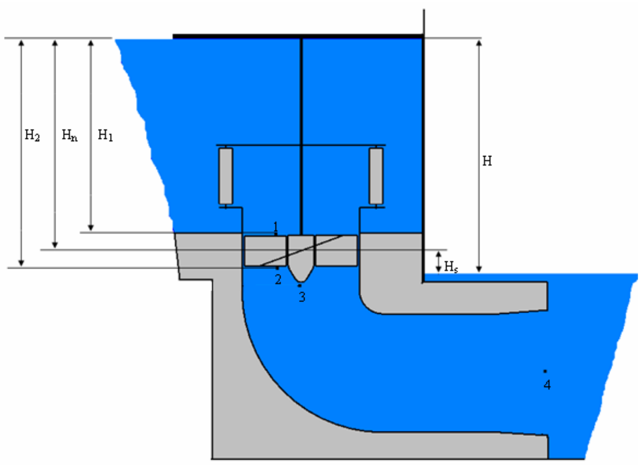

Figure 2: Sketch of a propeller turbine

3.2) Speed of the turbine

3.2.1 Specific speed

The different types of water turbines can be classified by their specific speed. The specific speed is a dimensionless parameter and characterizes the hydraulic properties of a turbine in terms of speed and discharge capacity; it is based on similitude rules. The specific speed is defined as:

$$n_s = \frac{n * \sqrt{Q}}{H_n^{\frac{3}{4}}} \qquad (2)$$

Where: Net head [m], Rational speed of the turbine [$\min^{-1}$]

The specific hydraulic energy 5.89 of machine can be established with the following equation:

$$E = H_n * g \text{ [J/kg]} \qquad (3)$$

Therefore, $H_n = 0.6$ m (4)

Due to statistical studies of schemes, F. Schweiger and J. Gregory established the following correlation between the specific speed and the net head for propeller turbines:

$$n_{QE} = \frac{2.294}{H_n^{0.486}} \qquad (5)$$

Since the rotational speed is unknown, the specific speed has to be calculated with the formula (5). Hence, a resulting specific speed (η_{QE} = 2.94 /sec and therefore rotational speed = 982 rpm)

3.2.2 Runaway speed

The runaway speed is the maximum speed which the turbine can theoretically attain; it is achieved during a null condition. Referring to standards of propeller, the following guidelines given in table 1 can be used to determine the runaway speed.

Table 1: Runaway speed

Turbine type	Runaway speed= n_{max}/n
Single regulated propeller turbine	2.0 – 2.6
Double regulated Propeller turbine	2.8 – 3.2

The turbine is supposed to work single regulated. Hence, a maximum runaway speed taking max coefficient = 2553 rpm

3.3) Runner diameter section

$$D_c = \frac{25.19 * (0.79 + 1.602 * n_{QE}) * \sqrt{H_n}}{60 * n} \text{ [m]} \tag{6}$$

After putting all the above calculated values the runner diameter D_c = 0.109 m

3.4) Hub diameter

$$D_i = \left(0.25 + \frac{0.0951}{n_{QE}}\right) * D_c \text{ [m]} \tag{7}$$

After putting the above calculated D_c in above equation the hub diameter D_i = 0.031 m

3.5) Blade characteristics of some different heads and discharges.

Table 2: Characteristics under different circumstances

De [M]	0.095	0.098	0.101	0.104	0.107	0.110	0.113	0.116	0.119	0.122	0.125	
Di [M]	0.028	0.028	0.029	0.030	0.031	0.032	0.033	0.034	0.035	0.035	0.036	Hn
P [Kw]	41.52	44.19	46.93	49.76	52.68	55.67	58.75	61.91	65.15	68.48	71.89	0.5
Q [M^3/S]	0.0106	0.0113	0.012	0.0127	0.0135	0.0142	0.015	0.0158	0.0166	0.0175	0.0184	
n[S-1]	1113	1079	1047	1017	988	961	936	912	889	867	846	
n_{MAX} [S-1]	2894	2806	2722	2644	2570	2500	2433	2370	2311	2254	2200	
P [Kw]	53.26	56.68	60.20	63.83	67.57	71.41	75.36	79.41	83.57	87.84	92.21	0.6
Q [M^3/S]	0.0113	0.0121	0.0128	0.0136	0.0144	0.0152	0.016	0.0169	0.0178	0.0187	0.0196	
n[S-1]	1130	1095	1063	1032	1003	976	950	925	902	880	859	
n_{MAX} [S-1]	2937	2847	2763	2683	2608	2537	2469	2406	2345	2287	2232	
P [Kw]	65.64	69.85	74.20	78.67	83.27	88.01	92.87	97.87	103.00	108.26	113.65	0.7
Q [M^3/S]	0.012	0.0127	0.0135	0.0143	0.0152	0.0161	0.0169	0.0179	0.0188	0.0197	0.0207	
n[S-1]	1145	1110	1077	1046	1016	989	962	938	914	891	870	
n_{MAX} [S-1]	2977	2886	2800	2719	2643	2571	2502	2438	2376	2318	2262	
P [Kw]	78.58	83.62	88.82	94.17	99.68	105.35	111.18	117.16	123.30	129.59	136.04	0.8
Q [M^3/S]	0.0125	0.0133	0.0142	0.015	0.0159	0.0168	0.0177	0.0187	0.0197	0.0207	0.0217	
n[S-1]	1159	1123	1090	1058	1029	1001	974	949	925	902	881	
n_{MAX} [S-1]	3013	2921	2834	2752	2675	2602	2533	2467	2405	2346	2290	
P [Kw]	92.00	97.90	103.99	110.26	116.71	123.35	130.17	137.17	144.36	151.73	159.28	0.9
Q [M^3/S]	0.0131	0.0139	0.0148	0.0156	0.0166	0.0175	0.0185	0.0195	0.0205	0.0215	0.0226	
n[S-1]	1172	1136	1102	1070	1040	1012	985	960	935	912	891	
n_{MAX} [S-1]	3047	2953	2866	2783	2705	2631	2561	2495	2432	2372	2315	
P [Kw]	105.86	112.65	119.65	126.87	134.29	141.93	149.77	157.83	166.10	174.58	183.27	1
Q [M^3/S]	0.0135	0.0144	0.0153	0.0162	0.0171	0.0181	0.0191	0.0202	0.0212	0.0223	0.0234	
n[S-1]	1184	1148	1114	1081	1051	1022	995	970	945	922	900	
n_{MAX} [S-1]	3078	2984	2895	2812	2733	2658	2588	2521	2457	2397	2339	
P [Kw]	120.11	127.81	135.76	143.94	152.36	161.03	169.93	179.07	188.46	198.08	207.94	1.1
Q [M^3/S]	0.0139	0.0148	0.0158	0.0167	0.0177	0.0187	0.0197	0.0208	0.0219	0.023	0.0241	
n[S-1]	1195	1159	1124	1092	1061	1032	1005	979	954	931	909	
n_{MAX} [S-1]	3108	3013	2924	2839	2760	2684	2613	2545	2481	2420	2362	

The table 2.allows the reader to get an overview of the main characteristics (P, Q, n, nMAX) of a Propeller turbine under different head and discharge circumstances.

IV. Development Of Prototype Model

1) Development of blades

Figure2: Views of a blade

The design of the blade in figure 2.does not just depend on the stress analysis but several other factors also play a significant role. The leading edge is kept thicker than the trailing edge for a streamlined flow and also to reduce the vibrations. This is incorporated in blade, by making it thicker near the flange and thinner towards the tip. In addition that, the blade has curved to take an advantage of the tangential velocity.

2) Development of Runner

The runner is the rotating part of the turbine, which includes the hub, blades and shaft. Casting from metal is probably too expensive except for mass production. Since this is a prototype building, the runner parts are developed by conventional manner. Some of the machine tools which are used to produce are portable grinder, general purpose lathe to machine shafts, hub, and welding machine to fabricate etc. The developed runner is shown in figure 3.

Figure 3: Runner

3) Development of draft tube

Draft tube is a long conical shape tube used to recover the kinetic energy at exit of turbine is shown in figure 4.

Figure 4: Draft Tube

4) Development of vanes

Guide vanes are used to give the flow, approaching the turbine blades, an initial swirl or tangential velocity component. The turbine blade changes the tangential velocity component of the flow, and it is this change, in tangential momentum, that produces the torque which further gives us mechanical output. Figure 5 shows the guide vanes.


Figure 5: Guide VanesFigure 6: Stay Vanes

5) Final prototype model of Ultra-Low head turbine

Figure 7 shows the prototype model of Ultra-Low head turbine. This developed model can benefit society for drinking water supply schemes, continuous power supply to help keep the rural hospital running normally, power supply to the street lights at night time.

Figure 7: Final Prototype Turbine

V. Conclusion

The main objective of this paper is to focus on the potential of micro hydro power development and to understand the designing procedure of a ultra-hydro system.

This paper deals with developed prototype model, at very low cost. The design of 0.2 kW developed using ultra-hydro plant prototype model can benefit to harness the unidentified hydro power potential which is available at K. T. weir (Kolhapur Type weir). The available hydro power potential can be used to supply and fulfil the demand of domestic water of nearby villages, for lightening the roads near K. T. weir.

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