DEVELOPMENT OF COST EFFECTIVE TURBINE FOR HILLY AREAS

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Micro hydro turbine, Turbine testing, Cross flow turbine

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ABSTRACT:

Tiny streams running in the hilly areas have a huge potential to generate additional power without impacting the environment. But in these areas there are limitations on transmission of power from other parts. Hence, it is a need of power available for the development of micro hydro power stations that can be used for local use. Small scale Micro hydropower stations combine the advantages of hydropower with those of decentralised power generation, without the disadvantages of large scale installations. Small scale hydropower has several advantages such as low cost distribution of energy, lower transmission loss, no huge environmental impacts as compared with large hydro power plant. Not depend on imported fuels and no need for expensive maintenance. It is a main source for better utilization of untapped hydro energy. Small scale hydropower can be used decentralised and be locally implemented and managed.

For this purpose, different types of turbines available for hydro power generation was studied. Among the different types of turbine available, cross flow turbine is most effective for the wide range of head. Even though the peak efficiency of a cross-flow turbine is somewhat lesser than that of other turbines, it has a flat efficiency curve under varying load. The turbine maintains its efficiency while the flow and load vary from 1/6th to the maximum. In the above scenario, a cross flow micro turbine is developed for matching the head range of 5m to 60m with the flow rate of 10lps to 70lps. The turbine has been developed such a way that it can be fabricated by any fabricator by using locally available resources and commissioned by any semi skilled labour. This way, the locally available untapped hydraulic resource can be efficiently utilized for generating energy.

For studying the performance of the turbine, a test setup was erected. The test setup consist of a reference flow meter, pressure tapping for upstream pressure measurement, a valve for flow control, a sump, and a pump for water circulation. A dynamometer was used for loading the turbine and a Torque transducer is used for measurement of the torque. Performances of turbine was studied at different guide vane opening for different heads. The obtained data was are used to plot hill diagram of the turbine.

1. INTRODUCTION

Hydropower is a very clean source of energy. It does not consume but only uses the potential energy of water. After use it is available for other purposes. The conversion of the potential energy of water into mechanical energy is a technology to get high efficiencies at optimum working range, where the design of turbine plays an important role. The use of hydropower can make significant savings on exhaustible energy sources.

In many of the hilly areas there are no electric grid. Good potential is available for the development of micro hydro power which can be used for local use. The upstream small rivers running in the hilly areas have a huge potential to generate the additional power without impacting the environment. In these areas there are limitations to transmission of power from other parts. So, good potential is available for the development of micro hydro power which can be used for local use without affecting environment. Small scale Micro hydropower stations combine the advantages of hydropower with those of decentralised power generation, without the disadvantages of large scale installations. Small scale hydropower has hardly any disadvantage: no costly distribution of energy, no huge environmental costs as with large hydro, not dependent on imported fuels and no need for expensive maintenance. Small scale hydropower can be used decentralised and be locally implemented and managed. Also, power generated with small hydro station can be used locally for agro-processing, local lighting, water pumps, small businesses etc.

2. HYDRAULIC TURBINES – SELECTION

The purpose of a hydraulic turbine is to transform the water potential energy to mechanical rotational energy. It is appropriate to provide a few criteria to guide the choice of the right turbine for a particular application. The potential energy in water is converted into mechanical energy in the turbine, by one of two fundamental and basically different mechanisms.

The water pressure can apply a force on the face of the runner blades, which decreases as it proceeds through the turbine. Turbines that operate in this way are called reaction turbines. The turbine casing, with the runner fully immersed in water, must be strong enough to withstand the operating pressure. Francis and Kaplan turbines belong to this category.

The water pressure is converted into kinetic energy before entering the runner. The kinetic energy is in the form of a high-speed jet that strikes the buckets, mounted on the periphery of the runner. Turbines that operate in this way are called impulse turbines.

The Water enters the turbine, directed by one or more guide-vanes located upstream of the runner and crosses it two times before leaving the turbine are called as cross flow turbine.

2.1 Impulse turbines

Impulse turbines where one or more jets impinge on a wheel carrying on its periphery a large number of buckets. Each jet shoots water through a nozzle with a needle valve to control the flow. They are generally used for high heads from 60 m to more than 1 000 m.

2.2 Reaction turbines

Reaction turbines are mainly classified into two. These are Francis and Kaplan turbines.

Francis turbines are reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. In this turbine the admission is always radial but the outlet is axial. Their usual field of application is from 25 to 350 m head.

Kaplan and propeller turbines are axial-flow reaction turbines; generally used for low heads from 2 to 40 m. The Kaplan turbine has adjustable runner blades and may or may not have adjustable guide- vanes. If both blades and guide-vanes are adjustable it is described as "double-regulated". If the guide-vanes are fixed it is "single-regulated". Fixed runner blade Kaplan turbines are called propeller turbines. They are used when both flow and head remain practically constant, which is a characteristic that makes them unusual in small hydropower schemes.

2.3 Cross-flow turbines

Cross flow turbine is known for wide range of heads overlapping those of Kaplan, Francis and Pelton. It can operate with heads between 5 and 200 m. It allows the water to pass through the runner and crosses it two times before leaving the turbine. This simple design makes it cheaper and easy to repair in case, runner brakes due to the important mechanical stresses. The Cross-flow turbines have low efficiency compared to other turbines and the important loss of head due to the clearance between the runner and the downstream level should be taken into consideration when dealing with low and medium heads. Moreover, high head cross-flow runners may have some troubles with reliability due to high mechanical stress.

It is an interesting alternative when one has enough water, defined power needs and low investment possibilities, such as for rural electrification programs. In the above scenario, a cross flow micro turbine is designed, developed and tested for its performance.

3. TURBINE DEVELOPMENT

In the hilly areas of Kerala state there are number of upstream rivers and small rivers are running with sufficient potential energy. Especially where there is no electric grids exist, good potential exist for development of micro hydropower for local use. Already some of the enterprising individuals are running such micro hydro turbines for electricity generation in a limited way, by sacrificing the safety standards. In most of the cases, the equipments are locally developed in a crude way. These equipments are not dependable and frequently fail, require constant attention for repairs, which render the unit unviable.

There is a necessity for introducing a cost effective, standard & reliable portable micro hydro turbine generator set for the rural application, since no reliable set is available in local market, except for some crude and locally manufactured sets or imported ones.

M/s Energy Management Centre, Trivandrum has collected data regarding the requirement of the range & rating of the micro turbines. The averaged head range proposed for micro turbine is from 20m to 50m with a power output in the range of 10 to 25kw. The type of turbine proposed was either cross flow or Pelton, due to simplicity of construction & maintenance, which could be managed by the local technicians. The final choice was for Cross flow at the first stage and then for Pelton subsequently.

Based on the above justification, a cross flow micro turbine having runner of 150 mm diameter and a length of 130 mm with guide vane was developed. This was developed to get a power output of 10kW. Special advantage of this design is that by just increasing the length of the turbine, we can get the power output increase proportionally. It is developed with an electric load controller. The turbine runners & guide vanes are made up of stainless steel. The turbine casting is made up of MS plate and shaft is made of carbon steel. Labyrinth seals and taper roller bearing are provided on the drive shaft. The prototype is designed to develop 7.5KW on 35m head and a discharge of ~40 lps. The specifications of the turbine are

Head	20-40 m	Area of jet	0.0155 m^2
Discharge	72-162 m^3/hr	Runner diameter	150 mm
Speed	800-1200 rpm	Runner width	130 mm
Number of blades	28		

The fabrication, machining & assembly of the turbine was done by a small scale manufacturer in Kerala, so that the local technicians can absorb the technology & duplicate the same depending on requirement. Thus the benefits like gains of development of reliable and cost effective micro hydro turbine at the local level, easy availability & maintainability, improving the skills of local technicians and generation of power for isolated hill areas, etc are expected.

4. TURBINE TESTING

Whenever a turbine is designed and developed, it is necessary to check for its performance in laboratory condition and or at site. Small hydro turbine can be tested in laboratory itself. Most of the bigger turbines, it is not possible to do testing in laboratory. In such cased a scale down model can be tested at laboratory and the original testing can be done at site. The turbine needs to be tested for understanding, its runaway speed and efficiency.

4.1 Runaway speed

When the plant is running at its rated condition, some times the load gets rejected from the grid. In this condition the runner attained at its maximum speed will be continued to run in the same speed without load for some time. Each runner, profile is characterized by a maximum runaway speed. This is the speed with which the unit can theoretically attain, in case of load rejection when the hydraulic power is at its maximum. Depending on the type of turbine, it can attain 2 or 3 times the nominal speed. During this condition the turbine has to run without any mechanical problems. Hence it is necessary to measure the runaway speed and check with the design data. For a good design practice, the measured runaway speed should be lesser than that of the design runaway speed.

4.2 Turbine efficiency

It is really important that the efficiency characterises of a turbine determine not only the ability of a turbine but also its hydrodynamic behavior. An average efficiency means that the hydraulic design is not optimum and that some major problems may occur (as for instance cavitation, vibration, etc.). This can strongly reduce the yearly power production and damage the turbine.

The first step is to carryout site tests to get this data. The other alternative is, performing laboratory tests on turbines geometrically similar to the industrial prototypes. In the case of small hydropower plants, the size of the models being tested is often quite close to that of the actual machines. The hydraulic behavior of the turbine may be observed over the whole extent of its operating range. It is thus possible to correct any possible shortcomings before the machine is actually built.

The efficiency guaranteed may be verified in accordance with the "International Code for the field acceptance tests of hydraulic turbines" (IEC 60041) or, if applied, in accordance with the "International Code for model acceptance tests" (IEC 60193). It is defined as the ratio of power supplied by the turbine (mechanical power transmitted by the turbine shaft) to the hydraulic power.

5. TEST PROCEDURE

For doing the performance evaluation of the selected cross flow turbine, a test setup is rigged up at Fluid Control Research Institute, Palakkad. The test setup consist of various equipments as briefed below. The line sketch of the test set up is shown in Plate A and the test setup is shown in plate B. The disassemble view of the turbine is as shown in plate C.

The test setup consist of a dynamometer coupled to the turbine, through a dynamic torque transducer. The dynamometer was used for loading the turbine and torque transducer coupled in between was used to measure the torque applied by the dynamo meter. A non contact type tachometer was used for measurement of the speed of the turbine. The turbine inlet was connected to the available test loop for simulating the required flow, and the outflow from the turbine was allowed to flow to the sump freely, without any draft tube. Water from the sump was allowed to pass trough the turbine using a pump. A 6” Electromagnetic flow meter was used for measuring the flow rate through the turbine. A precision pressure gauge was used for measuring the head of water just at the inlet of the turbine.

Sl. No	EQUIPMENT	SPECIFICATIONS	PURPOSE
1	Pump	Flow - upto 450 m^3/Hr Head – upto 100m	Water supply to test rig.
2	Electromagnetic Flow meter	Size - 6" Flow Range 15 -600m^3/hr	Flow Measurement
3	Precision Pressure Gauge	Range 0 – 100 m	Head measurement
4	Torque Transducer	Range 0 - 1000 N-m	Torque Measurement
5	Tachometer	Range 100-10000 RPM	Turbine Shaft Speed measurement
6	Dynamometer	Range - 11 kw Intermittent Rating – 150%	Loading instrument

For the experimental program, water was supplied from pump / constant head over head tank to the turbine at the required heads of 50kpa to 500kpa pressures. Valve available at the upstream side and by pass line was used to maintain the required head. The tests was done for different guide vane opening of 25%, 50%, 75% and 100%. Initially the turbine was allowed to run in its runaway speed for few minutes and the runaway data were collected. During the runaway testing the dynamometer was physically connected in the test loop and are in switched off condition. During the switched off condition, the dynamometer is freely rotating along with the turbine. Thereafter the turbine was loaded gradually by increasing the excitation voltage of the dynamometer. At each step, the upstream head, discharge, speed and torque produced by the turbine were noted down. From the test data the hydraulic power and mechanical power were calculated and the efficiency of the turbine was derived.

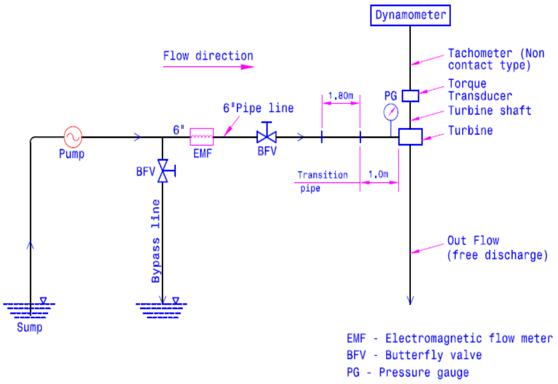


Plate A Schematic of test loop

Plate B Turbine under test

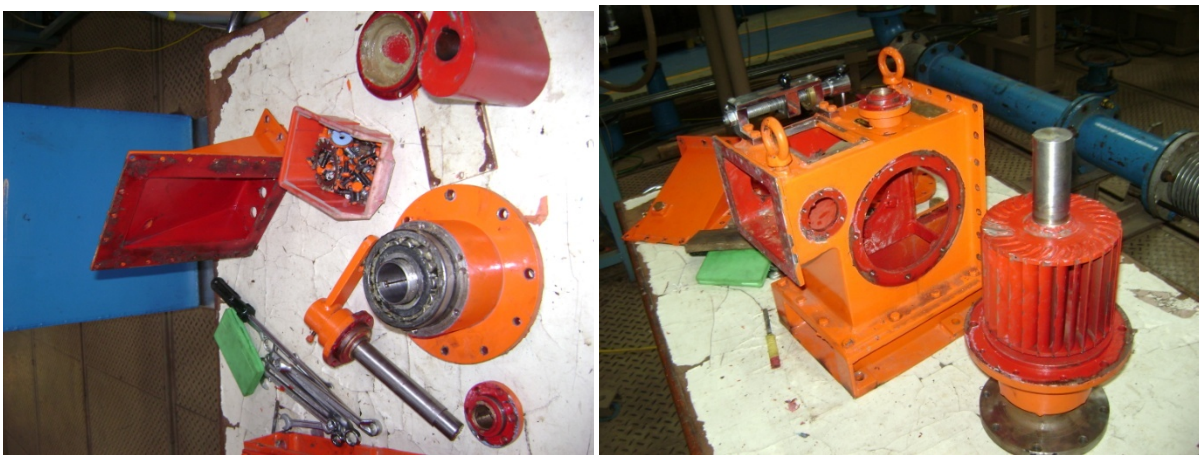


Plate C: Disassemble view of turbine

6. TEST RESULTS

Measurements were done at 25%, 50%, 75% and 100% of guide vane opening. At each condition hydraulic head, discharge, speed of the turbine, torque were measured.

At 25% guide vane opening data was collected for the head of 10 to 40 metre and speed range of 300 rpm to 2300 rpm. Maximum efficiency obtained was 24%.

At 50% guide vane opening data was collected for the head of 5 to 40 metre and speed range of 300 rpm to 2700 rpm. Maximum efficiency obtained was 30%.

At 75% guide vane opening data was collected for the head of 5 to 40 metre and speed range of 300 rpm to 3000 rpm. Maximum efficiency obtained was 44%.

At 100% guide vane opening data was collected for the head of 5 to 50 metre and speed range of 300 rpm to 3500 rpm. Maximum efficiency obtained was 55%.

From the measured parameters hydraulic power and mechanical power (Shaft power) are calculated and the efficiency of the turbine was computed as below.

$$Mechanical\ Power\quad (Shaft\ power) = \frac{2\pi NT}{60000} kw$$

Where

N – speed of the turbine in rpm,
T – torque in N-m

$$Hydraulic\ Power = \frac{9.81 x \rho\ h\ Q}{3600 x 10 x 1000} kw$$

where
ρ - density in kg/m^3
h – head in kpa
Q – Discharge in m^3/hr

For plotting the hill diagram, in z- axis the efficiency is plotted against the n11 in x –axis, and Q11 in y-axis.

n11 & Q11 are calculated as below

$$n11 = \frac{turbine\ speed\ x\ runner\ diameter}{\sqrt{net\ head}}$$

$$Q11 = \frac{discharge}{\sqrt{runner\ diameter}\ x \sqrt{net\ head}}$$

Where

N - Speed in rpm
Q - Discharge in m^3/hr
Runner diameter and head in metre,

The following Hill diagrams plots were developed and reported are as shown in plot 1 to 4

Plot 1: Hill diagram at 25 % guide vane opening
Plot 2: Hill diagram at 50 % guide vane opening
Plot 3: Hill diagram at 75 % guide vane opening
Plot 4: Hill diagram at 100 % guide vane opening

7. INSTALLATION

The very same prototype turbine has been installed at Gavi, Pathanamthitta Dt (Kerala Forest Development Corporation Ltd, under Kerala Forest Dept.). Test run for the installation is under progress. The photograph of the installation site and actual installations are as shown in plate D to F.

Plate D: Project site

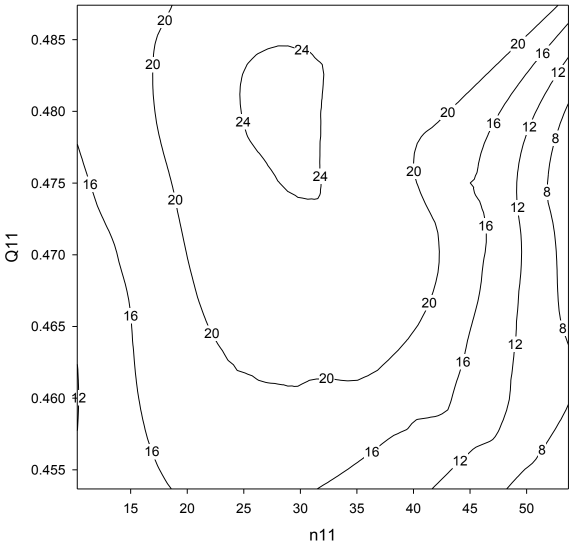
Plate E: Pipe line for inlet flow

Plate F: Actual installation

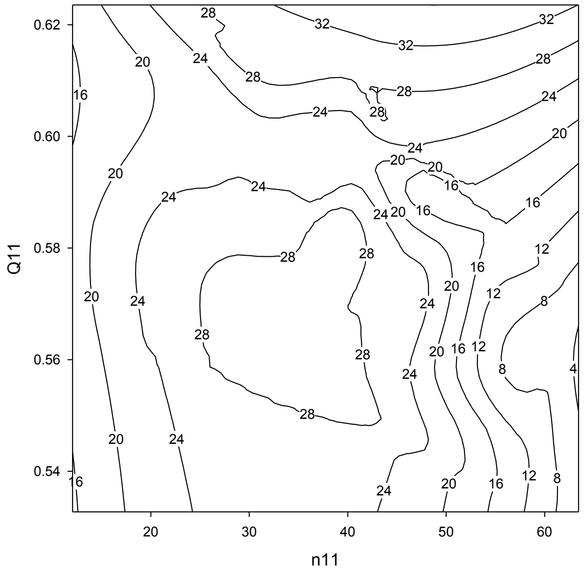
8. CONCLUTION

The test results are encouraging and the turbine is producing maximum efficiency of 55% with a head of 8 m to 10.5 m in 100% guide vane opening. Maximum efficiency was obtained with 100% guide vane opening. Maximum efficiency for different guide vane opening is as in plot 4.

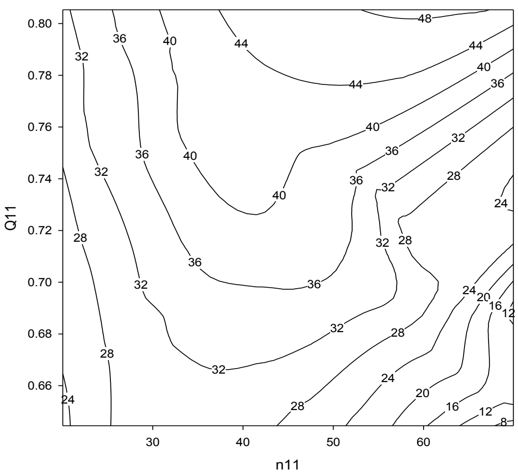
There is a further scope for improvement for improving the efficiency by modifying the guide vane profiles. It is suggested to study the efficiency with different guide vane design for further improvement.



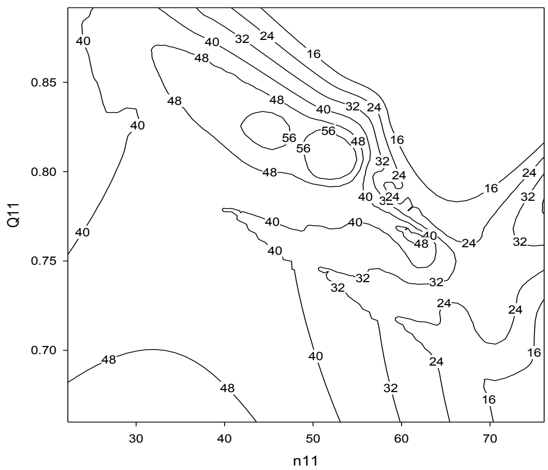
Plot 1: Hill diagram at 25 % guide vane opening



Plot 2: Hill diagram at 50 % guide vane opening



Plot 3: Hill diagram at 75 % guide vane opening



Plot 4: Hill diagram at 100 % guide vane opening

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