DEVELOPMENT AND TESTING OF A CROSS FLOW TURBINE

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SYNOPSIS

In many hilly areas where there is no electric grid, good potential is available for the development of micro hydro power. In such cases, small scale hydropower can be used as decentralised source of power which can be used to meet local requirement. Small scale Micro hydropower stations combine the advantages of hydropower with those of decentralised power generation, without the disadvantages of large scale installations. Micro hydro power becomes quite cost effective if it is locally implemented and maintained. Cross-flow turbines are considered as a favourable choice to meet the prevailing field conditions in general.

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 10 lps to 70 lps. The turbine has been developed such a way that it can be fabricated, commissioned and maintained easily by making the effective use of locally available resources like fabrication facility, semi skilled labour and available material. This way, the locally available untapped hydraulic resource can be utilized for generating energy in a cost effective manner.

Performance of the developed turbine was studied in detail using a dedicated test set-up. The required head at the upstream of turbine and flow through the turbine was generated by pumping of water from a sump. A calibrated Electro magnetic flow meter is fixed at the upstream side for the flow rate measurement. Pressure at the upstream of the turbine was measured using a high precision pressure gauge. Flow passed through the turbine was allowed to discharge freely into a sump. During the testing a control valve and by-pass arrangement available at upstream side of the turbine was used for achieving the desired flow and head. For output measurement, the turbine was coupled to an eddy current dynamometer through a Torque transducer. Experiments were repeated at different heads and different guide vane opening, and the performance is presented in the form of hill diagram.

The successful development of the cross-flow turbine is expected to benefit several households who were deprived of electricity. The turbine developed is presently available to public for installation.

1. INTRODUCTION

Hydropower is a very clean source of energy. It does not consume but only uses the water, after use it is available for other purposes. The conversion of the potential energy of water into mechanical energy is a technology with a high efficiency. The use of hydropower can make significant savings on exhaustible energy sources.

In many of the hilly areas there are no electric grids, good potential is available for the development of micro hydro power which 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 hardly any disadvantage: no costly distribution of energy, no huge environmental costs as with large hydro, independent from 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 issues 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 in to two. Those are Francis and Kaplan turbines.

2.2.1 Francis 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.

2.2.2 Kaplan Turbines

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 as 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 cheap and easy to repair in case of 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, especially where there are no electric grids, exist good potential 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 them 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 & locally manufactured sets or imported ones.

M/s Energy Management Centre, Trivandrum has collected general 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 and the output range is 10kw 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 is for Cross flow at the first stage and Pelton subsequently.

Based on the above justification a 10kw cross flow micro turbine with an electric load controller is developed. The turbine has a Stainless steel runner of 150mm diameter and a width of 130 mm with guide vanes made 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 design to develop 7.5kw on 35m head and a discharge of 160 m^3/hr. The specifications of the turbine are

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

The fabrication, machining & assembly of the turbine were 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 at off grid area for isolated hill areas, etc are expected.

4. TURBINE TESTING

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

4.1 Run away speed

When the plant is running at its rated condition, some time the load gets rejected from the grid. In this condition the runner attained its maximum speed and it will be continued to run in the same speed with out load for some time. Each runner profile is characterised by a maximum runaway speed. This is the speed, 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 problem. So it is necessary to measure the runaway speed and check with the designers recommended runaway speed. For good design practice, the measured runaway speed should be lesser than that of the maximum recommended runaway speed.

4.2 Turbine efficiency

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

The first is to carry out on site tests after putting the turbine into service. The second method consists of 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 behaviour 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 FCRI. The test setups consist of the equipments are as given below. The line sketch of the test set up is as shown in figure 1.

The test setup consist of a dynamometer is coupled to the turbine, through the dynamic torque transducer. The dynamometer was used for loading the turbine and torque transducer coupled in between was used to indicate the torque applied by the dynamo meter. A non contact type tachometer is used for measure 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 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 is connected used for measuring the flow rate through the turbine. A precision pressure gauge is connected 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 Uncertainty - +/- 0.3151 m^3/hr	Flow Measurement
3	Precision Pressure Guage	Range 0 – 100 m Uncertainty - +/- 0.03% of reading	Head measurement
4	Torque Transducer	Range 0 - 1000 N-m Uncertainty - +/- 0.26 of FS	Torque Measurement
5	Tachometer	Range 100-10000 RPM Uncertainty - +/- 0.3 RPM	Turbine Shaft Speed measurement
6	Dynamometer	Range - 11 kw Intermittent Rating – 150%	Loading instrument

For the test, 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 testing was done in 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’s were collected. During the runaway testing the dynamometer was physically connected in the test loop and is in switched of condition. During the switched of condition the dynamometer is freely rotating along with the turbine. Then 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 are noted down. From the test data the hydraulic power and mechanical power are calculated and the efficiency of the turbine was derived.

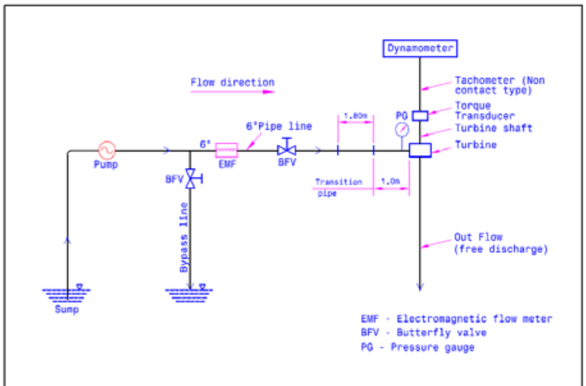


Fig.1 Schematic layout of test set-up

Plate A

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 derived as given 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

$$Hydraulic\ Power = \frac{9.81x\rho\ h\ Q}{3600x10x1000} kw$$

where

ρ - density in kg/m3 h – head in kpa Q – Discharge in m3/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

$$n11 = \frac{turbine\ speed\ x\ runner\ diameter}{\sqrt{net\ head}} \qquad Q11 = \frac{discharge}{\sqrt{runner\ diameter}\ x\sqrt{net\ head}}$$

Where

N - Speed in rpm, Q - Discharge in m3/hr

Runner diameter and head in metre,

The following plots were developed and reported

Efficiency speed Vs plot for different opening are shown in plot 1 to 4

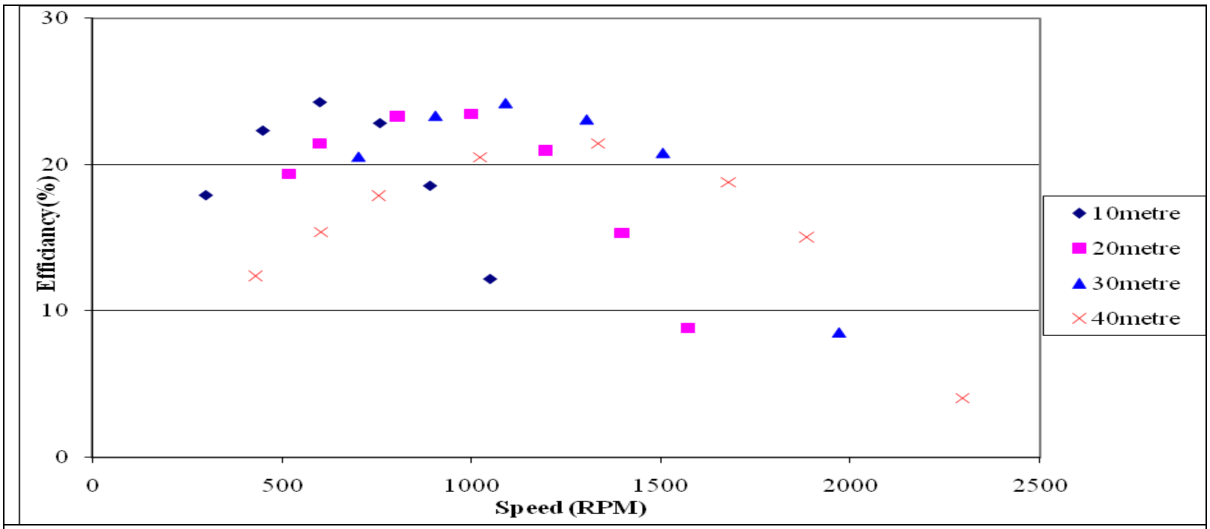
Plot 1: Speed Vs Efficiency at 25% opening Plot 2: Speed Vs Efficiency at 50% opening
Plot 3: Speed Vs Efficiency at 75% opening Plot 4: Speed Vs Efficiency at 100% opening

Hill diagrams are as shown in plot 5 to 8
Plot 5: Hill diagram at 25 % guide vane opening Plot 6: Hill diagram at 50 % guide vane opening
Plot 7: Hill diagram at 75 % guide vane opening Plot 8: Hill diagram at 100 % guide vane opening

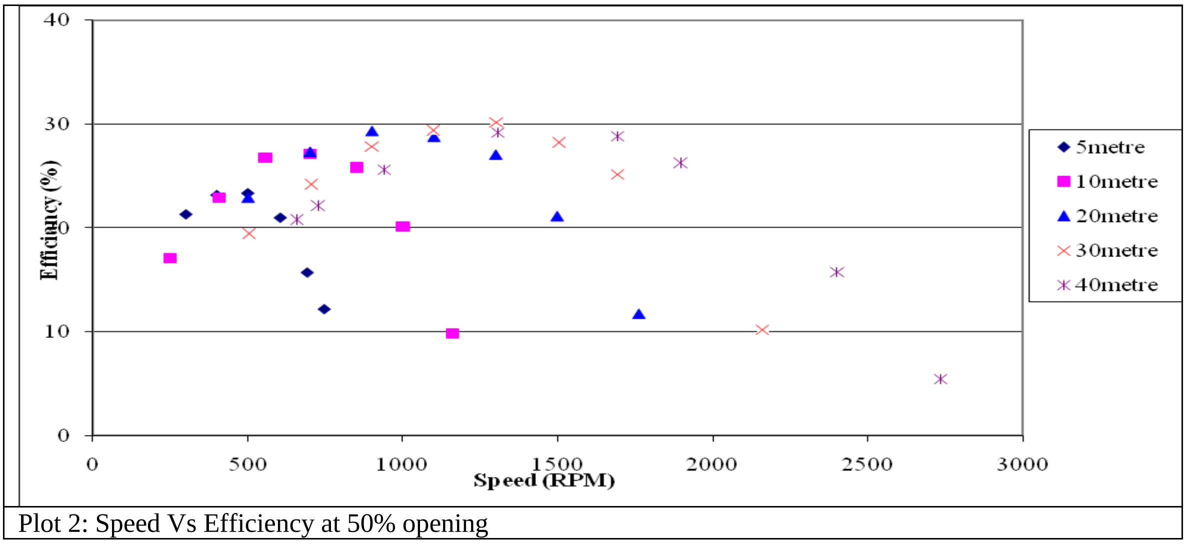
7. CONCLUSION

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 9.

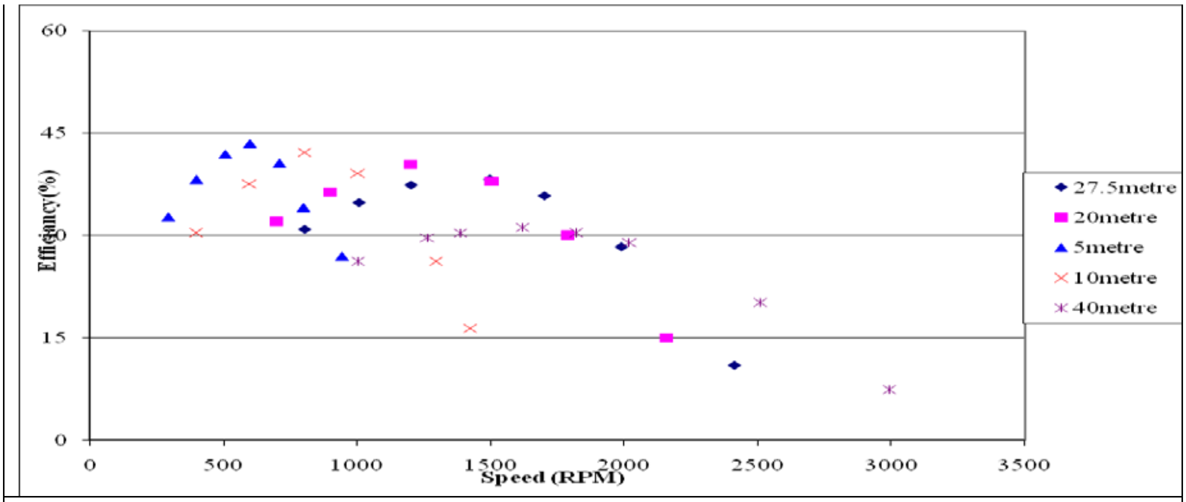
There is a further scope for improvement for improving the efficiency by modifying the guide vane profiles. It is suggested to study the efficiency with different guide vane design for further improvement.



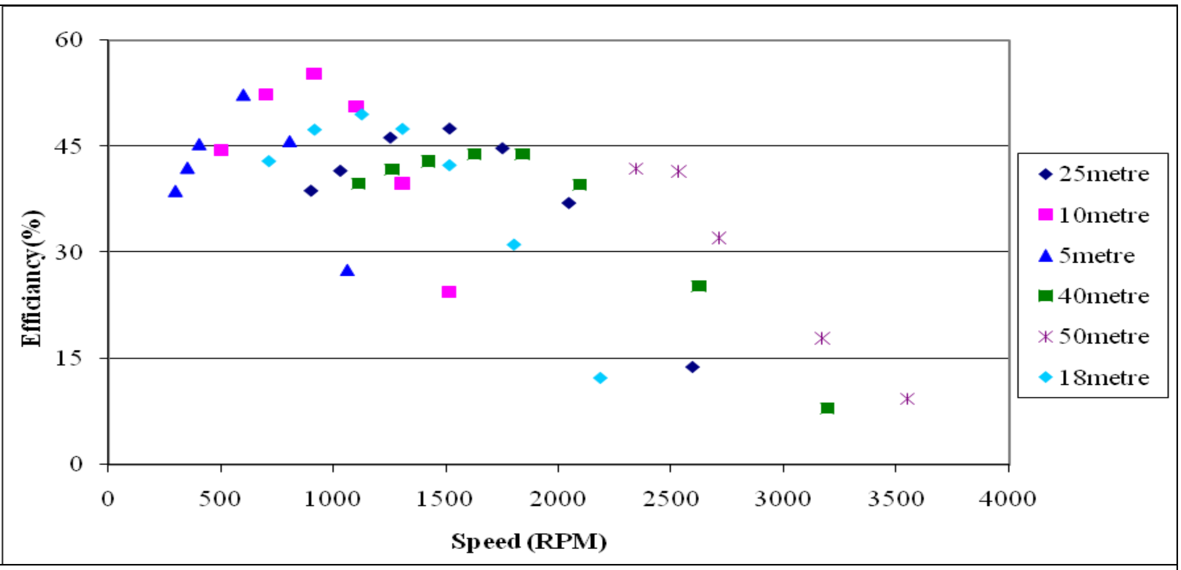
Plot 1: Speed Vs Efficiency at 25% opening



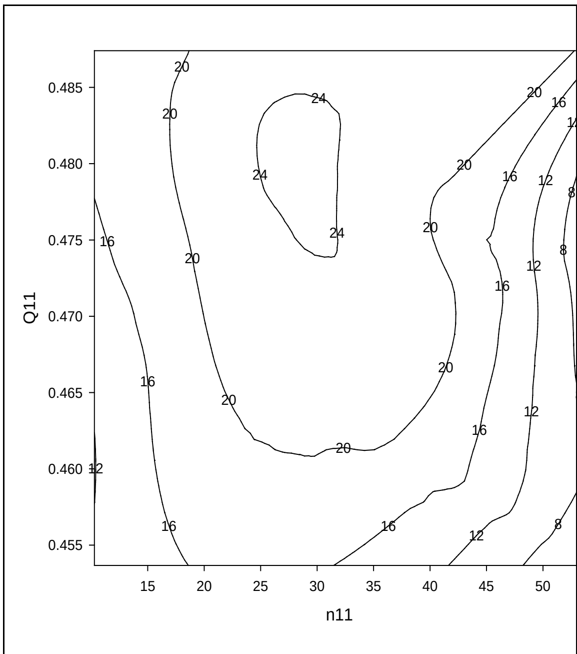
Plot 2: Speed Vs Efficiency at 50% opening



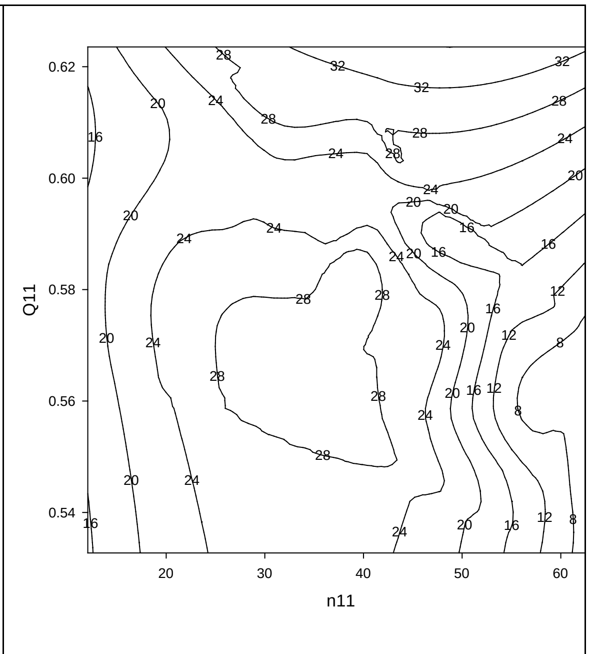
Plot 3: Speed Vs Efficiency at 75% opening



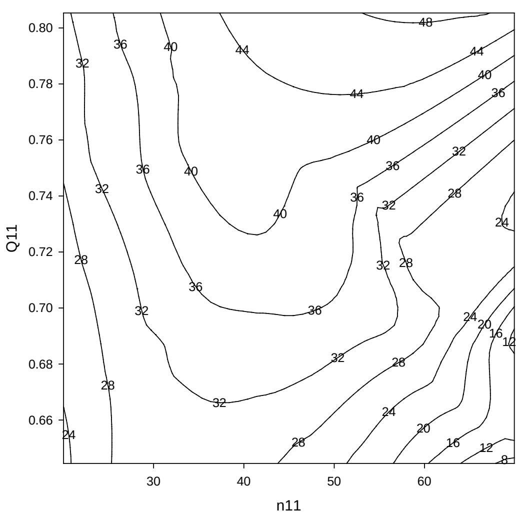
Plot 4: Speed Vs Efficiency at 100% opening



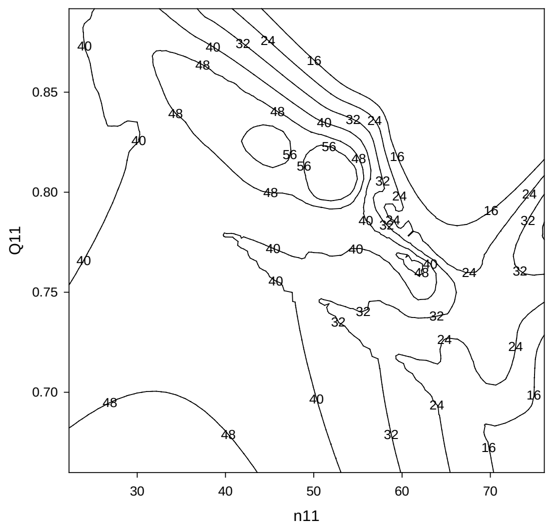
Plot 5: Hill diagram at 25 % guide vane opening



Plot 6: Hill diagram at 50 % guide vane opening



Plot 7: Hill diagram at 75 % guide vane opening



Plot 8: Hill diagram at 100 % guide vane opening

8. REFERENCE

1. Report on "Performance testing of Micro Hydro Turbine", A. Tamil Chandran, D.S. Anil Kumar, Jacob Chandapillai, Fluid Control Research Institute, Kanjikode, Kerala, India, April 2010.

2. Report on Performance testing of SHP stations " A guide for developers, Manufactures and consultants", Dr. Arun Kumar, Alternate Hydro Energy Centre, IIT- Roorkee, India, December 2009.

3. Report on "Standards/Manuals/Guidelines for small hydro development", Alternate Hydro Energy Centre, IIT- Roorkee, India Draft May 19, 2008.

4. Report on "Turbine and test facility design, Alden/NREC fish friendly turbine", Thomas C, etall Department of Energy, United States, September 2000.

5. "Micro Hydro turbine test facility at NERDC", T.A.Wickramasinghe, M.Narayana, International Conference on small hydropower- Hydro Srilanka, 22-24 October 2007.

6. "Design optimization of cross-flow hydraulic turbine", M. Barglazan, Scientific bulletien of the Politechnica, University Timisoaro, Volume 50(64), February 2, 2005.

7. Document on "Development of a reliable micro hydro turbine for off grid operation" M/s Energy management centre, Trivandrum, Kerala, India