A Review on Pump as Turbine for Micro Hydropower Plants

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Abstract-- **Hydropower is the top most renewable energy source and micro hydropower plant is one of the best solutions for energy crisis in remote, rural and hilly areas. In micro hydropower plants cost is equally important criteria as the efficiency. We can use centrifugal pump as the hydraulic turbine as it has advantage of being mass production in many countries throughout the world and low cost. As centrifugal pump used as turbine has no flow control mechanism so the part load efficiency is poor. This paper reviews the different work carried out by different researchers in the field of Pump as Turbine.**

***Index Terms*--Energy, micro hydropower, pump as turbine, review.**

I. INTRODUCTION

THERE is increase in energy demand in the world. Most of the countries in the world generate major portion of energy from the non renewable energy sources like thermal power plant, nuclear power plant etc. Non renewable energy sources have lots of disadvantages. As time goes this sources of fossil fuels is continue to deplete and also by use of this fossil fuel lots of changes in climate likes uneven rain, increase in the over all temperature of world etc. Now world is looking on maximum use of the renewable energy & top power development option to meet the increasing energy demand is “Hydro power”.

The water mill plays an important role for the last many decades for the development of hilly region. It is an important way to harness tremendous amount of hydro energy. But the energy harnessed by the water mills can be used as direct input to mechanical devices and cannot produce electrical energy efficiently. So harnessing of the hydropower in the form of electrical energy from the very small flow streams micro hydropower plants are required. In developing countries micro-hydro schemes have an important role to play in the economic development of remote rural areas, especially mountainous regions.

Micro-hydropower systems are small hydropower plants that have an installed power generation capacity of less than 100 kilowatts (kW). Many micro-hydropower systems are of “run of river” type which means that no large dams or water storage reservoirs are built and no land is flooded. In India the micro hydro potential exist in the Himalayan and sub Himalayan region. There is large number of small water sources in north India. In the past decades water mills are being used, which comes under the micro hydro range. A micro hydro power system can be developed either from natural resources as run of river scheme or by man-made structure as dam.

Micro-hydropower is a practical and potentially low-cost option for generating electricity at remote sites, particularly for small villages in hilly areas Micro-hydropower systems provide energy continuously, 24 hours a day. In remote locations where electricity is provided by diesel generators, micro-hydropower offers an opportunity to directly replace a fossil fuel with a renewable energy source. One way to reduce the equipment cost is to use a standard pump unit as an alternative to a conventional turbine.

The brief details about Pump in turbine mode with its advantages and limitations are discussed. The different work carried out by different researchers in the field of Pump as Turbine (PAT) is presented. Also the current scenario to use Pump as Turbine is presented.

II. PUMP AS TURBINE

1) General

Pump as turbine can be used in village schemes in developing countries where the main electric requirement is lighting. In some cases, when electric energy is needed only for lighting, the water supply can be used during daytime for irrigation. When operated in reverse mode standard pump units have important advantages over conventional turbines for small-scale hydropower generation like mass production of pumps while turbines are designed for each site; integral pump and motor can be purchased and used as a turbine-generator unit; available for a wide range of heads and flows; available in large number of sizes; low cost; short delivery time; spare parts are easily available; easy installation. Its disadvantages are as yet poorly understood characteristic of turbine performance, lower typical efficiencies, unknown wear characteristics, and poor part flow efficiency, flow rate is fixed for a particular head.

2) Range of heads and flows

Pump as turbine can be used over the range covered by Pelton and small Francis turbines. However, for high head and low flow applications, a Pelton turbine has a greater efficiency than a PAT, at the same cost. Head-flow ranges for various turbine options are shown in Fig. 1.

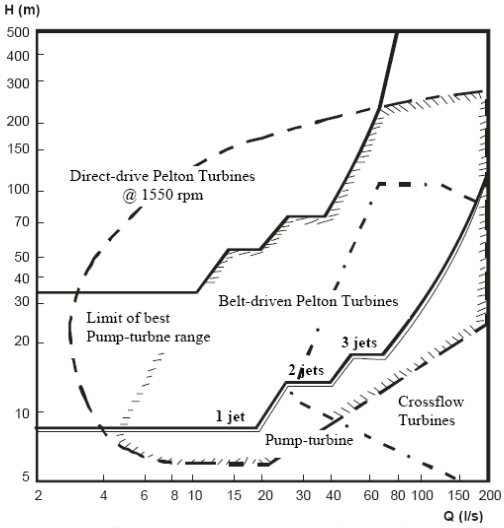

Fig. 1. Head-flow ranges for various turbine options [1].

The use of pump as turbine is limited by the availability of a fixed flow rate, and is therefore suitable for sites where there is a sufficient supply of water throughout the year. Long-term water storage is not generally an economically viable option for a micro-hydro scheme because of the high cost of constructing a reservoir.

3) Types of pump used as turbine

Virtually any type of pump may be used as turbine. In comparison with centrifugal and mixed flow pumps, axial flow pumps are less advantageous in that respect. The vast field of different pump designs and power ranges provides a suitable PAT for almost any application with heads from about 10 m up to several hundred meters. Large flows may be accommodated with double-flow pumps. Even submersible pumps may be used as PAT, which when integrated in the pipe system, are completely hidden away underground. Efficiencies of pumps used as turbines may be the same as in pump mode but are more often several percent (3 - 5%) lower.

4) Method for selection of pump as turbine

The following procedure may be adopted for selection of a pump to be used as turbine for a given site data:

i. Decide the values of rated head (H_t in m) and rated discharge (Q_t in m^3/s) for turbine from given site data.
ii. The above data yields the value of available hydraulic power $P_t = \rho gQH$ in W.
iii. Keeping this in view select the value of speed of generator and also the speed of pump.
iv. Find the value of specific speed for turbine data by the following formula:

$$N_{st} = \frac{N_t \sqrt{Q_t}}{H_t^{3/4}}$$

v. Examine whether it is desirable to use double suction pump. This should be done wherever possible because shaft of double suction pump experiences negligible thrust. Neglecting the effect of efficiency and assuming $\eta_t = \eta_p$ we get:

$$N_{sp} = N_{st} \text{ for single suction pump,}$$

$$= \frac{N_{st}}{\sqrt{2}} \text{ for double suction pump}$$

vi. Find the value of conversion factors q and h from test theoretical curves and based on them find the values of discharge and head of the pump. (Q_p & H_p)
vii. Find from pump catalogues whether pump for chosen values of Q_p, H_p and η_p is available. If not select suitable pump speed for which a pump is available to match desired Q_p and H_p. Find new specific speed and check the values of conversion factors for the same. With little trial and error, it will be possible to select a pump.
viii. In all cases recheck all the values for selected pump and find out the out put power.

5) Hydraulic losses in pump and turbine mode

When fluid passes from the impeller, there occur friction and shock losses. Hence, ideal energy transfer from the impeller to fluid as per the Euler's equation is not achieved. Total head generated by the pump is always lower than the ideal head. This reduction of head is called as hydraulic efficiency of pump. It reverse mode, PAT operates at optimum flow conditions, an increased pressure must act on the PAT. Therefore friction and shock losses must added to the ideal head given by the Euler's equation. Other losses in pump consist of leakage of fluid from high pressure side to low pressure side reducing the total discharge. These losses are called volumetric losses and efficiency corresponding to these losses are called volumetric efficiency. Similar losses are appears in turbine mode. The difference in hydraulic losses in pump and turbine mode is shown in Fig. 2.

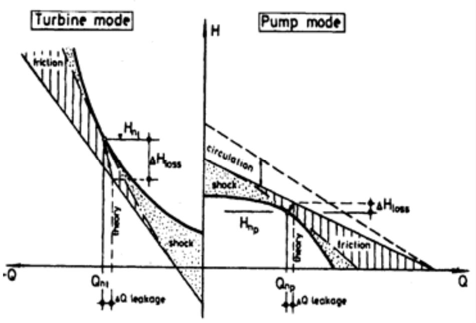

Fig. 2. Difference in hydraulic losses in pump and turbine mode [1].

III. LITERATURE REVIEW

S. Natanasabapathi and J. Kshirsagar [2] described the investigations of Pump as Turbine using numerical approach. They described various problems faced during modeling and the approaches used to resolve the problems. The unstructured mesh concept in CFX 5.6 resolved the complex blocking approach used in structured mesh. The geometries were modeled using Pro-E solid modeler and transferred to CFX. The results from the analysis were encouraging. The predicted performance showed a good trend with the experimental test results. The Head drop across the turbine was matched with the experimental values while there was a deviation in the efficiency computed from CFD at discharges away from BEP. Three dimensional computational model of PAT is shown in Fig. 3.

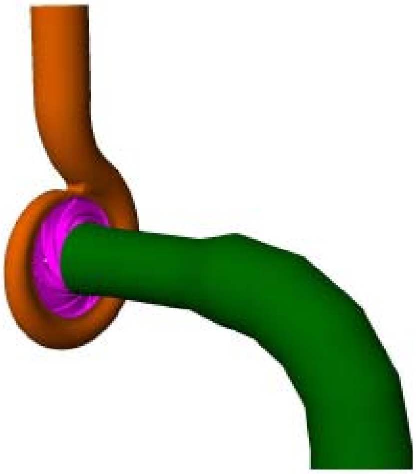

Fig. 3. 3-D computational model of PAT [2].

A. Williams and A. Rodrigues [3] carried out CFD analysis of 5 kW capacity pump working under 22 m head and 2 LPS discharge. They simulated the pump in turbine mode by enlarging the impeller suction eye diameter and found reduction in head with negligible change in power. The effect of variation in suction eye diameter is shown in Fig. 4.

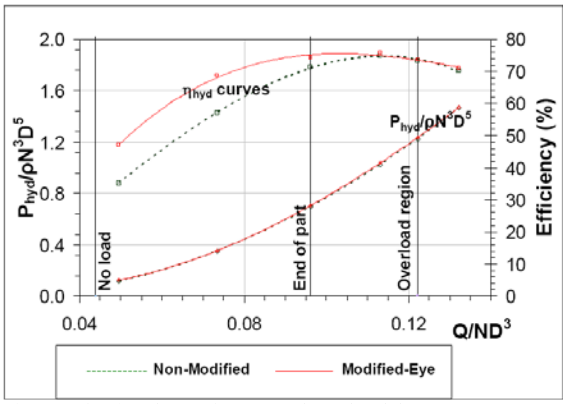

Fig. 4. Enlarging the suction eye-reduces head, but not power [3].

S. Chuenchooklin [4] carried out research on the development of Pico-hydropower plant for a farming village in Thailand. He explained hydro technology for production of electricity in a small village in hilly or mountainous region. His results showed that the produced electricity was enough for the electricity consuming with indoor electrical appliances such as electric light and some house-ware appliances. He also discussed the variation in efficiency with season depending on the availability of water.

M. Suarda et al. [5] determined performance of a small centrifugal volute-pump as turbine at the maximum head of the pump before and after modification of impeller tips of the pump at various capacities. The experiments were performed by grinding the inlet ends of the impeller tips of the pump to a bullet-nose shape to preclude excessive turbulence for efficiency consideration. Then testing is carried out by operating the pump as turbine at the maximum head of the pump (i.e.13 meter) and at various capacities. The modification in impeller is shown in Fig. 5 and effect of modifications on power and efficiency are shown in Fig. 6.

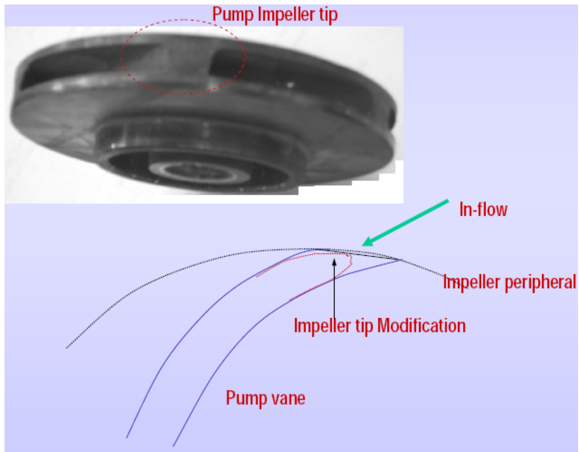

Fig. 5. Modification in impeller tips [5].

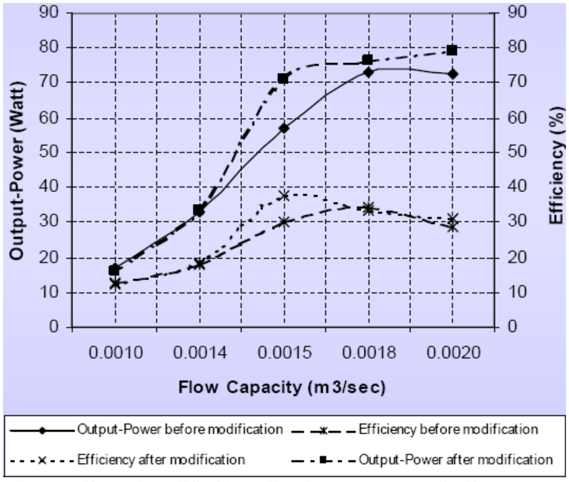

Fig. 6. Effect of modified impeller tips on power and efficiency [5].

A. Agostenelli and L Shafer [6] over the year tested many pump as turbines. They reported that pumps operating in turbine mode yield good efficiencies and can be run even more efficiently by operating multiple pumps of various sizes rather than one large hydraulic turbine. They mentioned various advantages of PAT viz. pumps are more readily available in many sizes; they are several generation ahead of conventional hydraulic turbines in cost effectiveness; pumps are less complex, making them easier to install and maintain and simpler to operate; and pumps are available in a broader range of configurations than conventional hydraulic turbines e.g. wet pit, dry pit, horizontal, vertical, submersible etc.

S. Derakhshan and A. Nourbakhsh [7] achieved the best efficiency point of an industrial centrifugal pump running as turbine using theoretical analysis. The pump was simulated in direct and reverse modes by computational fluid dynamics. For experimental verification of theoretical and numerical results, the pump was tested as a turbine in a test rig established in laboratory. All required parameters were measured to achieve complete characteristic curves of the reverse pump. The theoretical and numerical results were compared with experimental data and some CFD methods. The experimental setup is shown in Fig. 7 and measured & numerical head number and efficiency curves in pump mode are shown in Fig. 8.

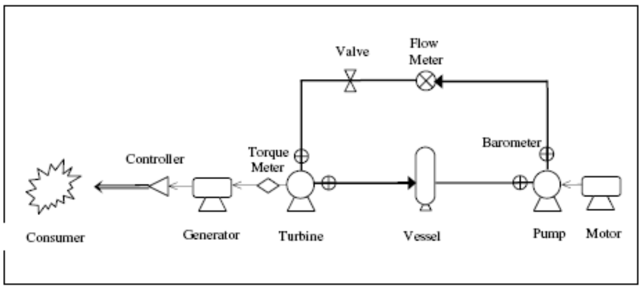

Fig. 7. Experimental setup for PAT [7].

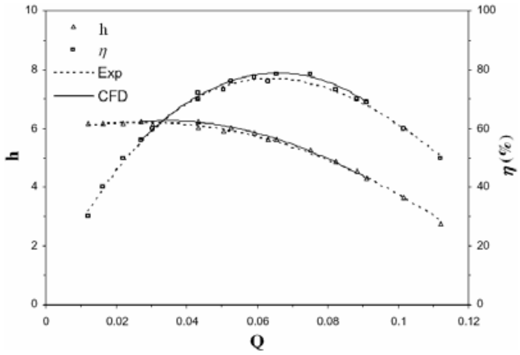

Fig. 8. Measured and numerical head number and efficiency curves in pump mode [7].

L. Shafer [8] showed three types of installation of pump as turbine for different range of head namely: wet pit propeller or mixed flow pump as turbine (less than 75 feet head), dry pit installation (75-200 feet head) and Horizontal split-case pump (200-500 feet head). He drawn the performance curves for these cases and compared them.

S. Derakhshan and A. Nourbakhsh [9] tested several centrifugal pumps (Ns < 60 (m, m^3/s)) as turbines. They derived some relations using experimental data to predict the best efficiency point of a pump working as a turbine based on pump hydraulic characteristics. The dimensionless head, discharge and efficiency curves in pump and turbine mode are shown in Fig.s 9-11 respectively.

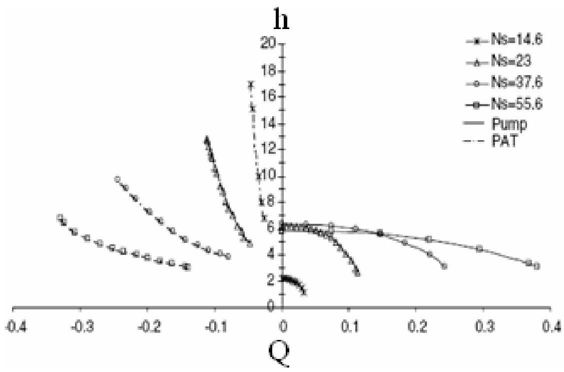

Fig. 9. Dimensionless head curves of tested PATs in pump and turbine modes [9].

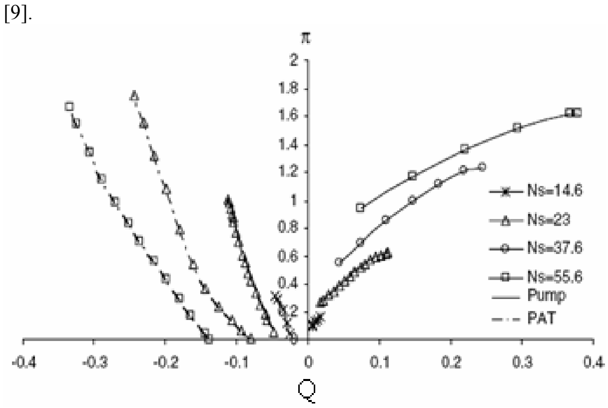

Fig. 10. Dimensionless power curves of tested PATs in pump and turbine modes [9].

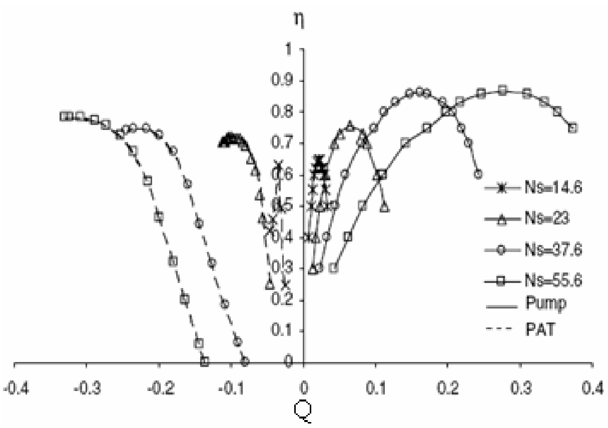

Fig. 11. Dimensionless efficiency curves of tested PATs in pump and turbine modes [9].

U. S. department of the interior bureau of Reclamation [10] developed the monograph which presents guidelines for designers who plan or maintain pump-turbine installations. Data were presented on recent installations of pump-turbines which included figures showing operating characteristics, hydraulic performance, and sizing of the unit. Specific speed, impeller/ runner diameter, and the best efficiency head and discharge were selected as the criteria that characterize the unit performance.

A. Williams [11] described that when pump-as-turbine used with an integral induction motor, they can be installed as a combined turbine and generator unit. A standard design of Induction Generator Controller (IGC) enabling these units to be used for isolated micro hydro schemes. The characteristics of the generator and water turbine were such that the controller also produces good frequency regulation. Single-phase induction motors can be used as stand-alone generators, but problems may be experienced in achieving excitation and in determining the size and arrangement of the capacitors required.

R. Sonia and J. Kshirsagar [12] revealed that the numerical model of PAT exhibits very good characteristics with a maximum operating efficiency of 83.10% while operating at a speed of 1450 rpm. The value of peak efficiency at different operating speed was different but occurs at constant Q/ND^3 of 0.40. The maximum efficiency for 800 rpm, 900 rpm and 1000 rpm were 81.4%, 82.7%, & 83.3% respectively. The similarities between experimental and numerical results were satisfactory. The difference between the experimental data and numerical simulation results were removed through further improvement in the CFD simulation by using finer mesh, numerical scheme and turbulence model. The details of loss and head distribution in different domains are given in Table 1.

TABLE I
LOSS AND HEAD DISTRIBUTION IN DIFFERENT DOMAINS [12]

	Parameter(m)	Discharge Q/Q_{bep}				
		0.6	0.8	1.0	1.2	1.4
1	Losses in casing	0.59	0.14	0.06	0.03	0.04
2	Net total head across the impeller	3.61	7.83	12.49	16.90	22.32
3	Losses in impeller	1.27	1.08	1.34	2.03	3.74
4	Losses in draft tube	0.97	0.42	0.54	1.10	2.01
5	Total input head in turbine	6.43	9.46	14.13	20.04	28.10

S. Joshi and L. Chang [13] presented a simple approach to predict PAT performance which helps in pump selection. A micro hydro site producing 25 kW electric power from 5.5 m of gross head was presented as a case study. The approach was simple and can be generalized. The case study was based on experimental data from only 3 pumps. Variation in different quantities with load variation was simulated. Also variation in generated voltage with excitation capacitance was done.

C. Isbasoiu et al. [14] given basic information of pump used as turbine, like range of head and flows, performance curves when operating as pump and as turbine, system control with pump as turbine, selection of pump as turbine for particular site and operation of a pump as turbine.

P. Singh and A. Rao [15] evaluated the field performance of pump-as-turbine unit for a 10kW capacity micro hydro at Kinko, Tanzania and compared the predicted and field hydraulic characteristics with uncertainty bands for field trials. The paper advocated the importance of proper selection of an optimum pump-as-turbine and simulation of its complete operating characteristics for the success of any micro hydro project.

J. Steller and A. Adamkowski [16] illustrated that identifying home manufactured impeller pumps suitable for energy generation purposes. They determined performance characteristics for different types of pump likes, mixed flow pump, centrifugal pump, multi-stage radial pump, triple-stage pump and established general relationships between best efficiency (bep) parameters in both modes of operation. Low-cost modifications of the flow part geometry aimed at enhancing performance characteristics in turbine mode of operation.

M. Gantar [17] described that the propeller pumps which are usually applied at irrigation, drainage and in energy object, however they can also run as energy recovery turbine. A series of test on the model of pump carried out in pump and turbine running condition. Beside hydraulic, energy and cavitations characteristics, axial trust and torsion movement on impeller blade were shown.

IV. CONCLUSION

In micro hydro range cost is equally important criteria as the efficiency of turbine due to the low capacity of plant. The experience cumulated so far shows that pump in turbine operation may be economically justified in case of stable hydrological conditions, low capacities and discharges in some micro hydropower plants. Therefore it is highly desirable to encourage pump manufacturers to test at least some of pumps also in turbine mode of operation. Providing access to pump versions modified for the purpose of possible use in turbine mode of operation may further widen their markets and contribute to better utilization of available micro hydropower potential.

V. REFERENCE

[1] R. Pandey, M Tech Dissertation on *Performance Analysis of Modified Pump As Turbine,* 2008, AHEC, IITR

[2] S. R. Natanasabapathi, and J. T. Kshirsagar, "Pump As Turbine - An experience with CFX-5.6".

[3] A. Williams and A. Rodrigues, *The Performance of Centrifugal Pumps as Turbines and Influence of Pump Geometry.*

[4] S. Chuenchooklin, "Development of Pico-hydropower Plant for Farming Village in Upstream Watershed, Thailand" Topentang, October 11-13, 2006.

[5] M. Suarda, N. Suarnadwipa, and W. Adnyana, *Experimental work on modification of impeller tips of a centrifugal pump as a turbine*

[6] A. Agostenelli and L. Shafer "Centrifugal pumps as hydraulic turbines"

[7] S. Derakhshan and A. Nourbakhsh "Theoretical, numerical and experimental investigation of centrifugal pumps in reverse operation," Experimental Thermal and Fluid Science 32, pp. 1620-1627, 2008.

[8] L. Shafer "Pumps as turbines: systems and application"

[9] S. Derakhshan, and A. Nourbakhsh, "Experimental study of characteristic curves of centrifugal pumps working as turbines in different specific speeds" Experimental Thermal and Fluid Science 32, pp. 800-807, 2008.

[10] R. Stelzer, and R. Walters, *Estimating Reversible Pump-Turbine Characteristics,* United states department of the interior bureau of reclamation Engineering monograph no 39, 1977, pp. 1- 48.

[11] A. Williams, "Pumps as turbines for low cost micro hydro power," WREC, pp. 1227-1234, 1996.

[12] S. Raval and J. Kshirsagar, "Numerical simulation on a pump operating in turbine mode," 23rd International Pump Users Symposium, pp. 21-27, 2007.

[13] S. Joshi, and L. chang "Development of a stand alone micro-hydro system using pump as turbine technology for low head sites in remote areas," 20th International Power System Conference, pp. 1-7, 2005.

[14] E. Isbasoiu, D. Bucur, C. Ghergu, and G. Dunca "Using standard pumps as turbines," CEEX, pp. 96.1-96.6, 2007 .

[15] P. Singh, and A. Rao "Performance evaluation of the pump as turbine based micro hydro project in Kinko village, Tanzania" Himalayan Small Hydropower Summit, Dehradun, pp. 140-141, Oct. 2006.

[16] J. Steller, A. Adamkowski, Z. Stankiewicz, A. Lojek, J. Rduch, and M. Zarzycki, "Pumps as turbines for hydraulic energy recovery and small hydropower purposes in Poland".

[17]M. Gantar, "Propeller pumps running as turbines," Conference on Hydraulic Machinery, Ljubljana, 237-248, Sep. 1988.