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GUIDED PUMP-AS-TURBINE: DESIGN AND DEVELOPMENT FOR PICO-LEVEL ENERGY GENERATION

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Abstract- The Project- "Guided Pump as Turbine" aims to further research in the field of Pico Hydel Projects. This has been accomplished by building a prototype "Pump as Turbine" apparatus consisting of a centrifugal pump running as turbine to generate power. Along with these apparatus the centrifugal pump is converted to guided-pump where stator is appropriately introduced into the system. The purpose of this is to enhance the efficiency of the system. The project holds tremendous benefit by way of providing power/electricity to small communities dwelling in regions having potential for pico-scale hydel power exploitation. The development of the prototype is accomplished under a controlled environment. Head availability and the flow rate are the two measures against which it is optimized. Furthermore, the effect of introducing guide vanes, hitherto unknown, was investigated and analyzed. Analysis was done first on power and efficiency of produced by technology and then on a dimensionless basis to facilitate scaling up/down of PAT capacity for further research. The project has accomplished a detailed analysis of the characteristics of a pump running as a turbine, over a variety of conditions, with and without guide vanes.

Keywords- Guide-Vane, PAT; Pico-Genration; Hydro Power; decentralized energy genration; Pump as Turbine

I. INTRODUCTION

A. Motivation

There are various sites where head and flow rate is very less and using turbine to harness it is very costly and uneconomical. For such small sites efficiency is not an issue. Running costs for such schemes are very low, but the initial capital cost can be relatively high and any reduction in equipment costs will make the technology more accessible. One way to reduce the equipment cost is to use a standard pump unit as an alternative to a conventional turbine. Pumps are mass-produced, and as a result, have the following advantages for micro-hydro compared with purpose-made turbines:

- Integral pump and motor can be used as a turbine and generator set
- Available for a wide range of heads and flows
- Available in a large number of standard sizes
- Short delivery time
- Spare parts such as seals and bearings are easily available Easy installation - uses standard pipe fittings

B. Pico-Generation

Pico-generation is defined for the range of generation with capacity less than 20 kW of energy. The technique is widely used in decentralized energy source which is effectively fulfilling the need of local population.

C. Need of Innovation

In many developing countries, mountainous regions tend to be underserved with regard to availability of grid electricity. The low density of population and difficult terrain make it costly and impractical for the central grid to reach the more inaccessible villages and hamlets. In a significant proportion of these there exist numerous hydrological resources such as small streams etc. Due to the relatively small head and volume flow rates the use of conventional turbines are not feasible. This calls for a new approach to energy generation or more specifically distributed energy generation. This project attempts to achieve pico-hydel generation through at the lowest possible cost.

D. Introduction of Innovation

Turbines are custom made, hence, expensive and out of question for the rural poor. However, if we use a pump (which is mass produced and hence, pretty cheap) we have a clean, green and a sustainable solution for the power needs of the rural people. The scale of generation is targeted to household uses and hence ranging from 400w-5kw.

II. LITERATURE REVIEW

(A) The research paper by A A Williams[7] has been summarized as follows:

- Turbine tests on 35 pumps of various types and sizes
- Relative merits and demerits of eight different methods for theoretical analysis of pumps used as turbine are compared.

Although, all of them are based on the data for pump performance at best efficiency, there is a lot of variability in results.

- Guide vanes have not been used.
- It has been concluded that Sharma's method matches the experimental results most closely. Though, even after using Sharma's method, the predictions were outside the acceptable limits, for about 20 per cent of the pumps for which test data were available.

(B) Summary of research paper by Nourbakhsh et al [8]:

- In this paper, several centrifugal pumps ($N_s < 60$ (m,m³/s)) were operated as turbines. Using experimental data, some relations were derived to predict the best efficiency point of a pump working as a turbine,
- Four industrial centrifugal pumps with specific speeds from 14 to 56 (m,m³/s) were selected for experiments.
- These pumps had input power, head and flow rate up to 30 kW, 25 m and 0.15 m³/s, respectively
- Results showed that for optimum working, PAT requires higher flow rates and heads than a corresponding pump working normally.
- Prediction of BEP of a PAT:

Figure 1: Dimensionless BEP of tested PATs

(C) Research Paper chronicling Development of Pico-hydropower Plant for a Farming Village in Upstream Watershed, Thailand[9]:

- Development of Pico-hydropower plant for a farming village in Thailand was accomplished.
- A 3-phase motor producing electricity of 380 volts at revolution of 1500 rpm was used. Motor specifications: effective head 8.4 meters, flow rate of 15 liters per second.
- Electrical power production of 644 watts.
- The design of the systems for selecting reversed centrifugal pump as turbine was

based on Sharma as the following equations of discharge and head (Sharma, 1985):

$$Q_t = Q_{bmp} / (n_{max})^{0.8} \dots (i)$$

Where: n_{max} is maximum efficiency of pump, Q_t is the average flow rate through the pump (cms), Q_{bmp} is the maximum flow rate through the pump (cms)

$$H_t = H_{bmp} / (n_{max})^{1.2} \dots (ii)$$

Where: H_t is the average head of water above pump (m) H_{bmp} is the head of water above pump at maximum efficiency (m)

The technique is till time is used for micro-generation and installed in linked areas. The prior works studied in this project are

- The Hiwassee Power Plant was the first one to use the reversal pump turbine mechanism. To control the peak power requirement, they decided to install a pump through which water is pumped in non peak season to a reservoir and at the time of peak power requirement the same water rotates the same pump as turbine to produce power. After 16 year of research they finally putted their second unit as reversal pump-turbine in 1956[1].
- 1966, Derek Hartland received a patent[2] for inventing a means of injecting water into draft tube with substantial amount of tangential component.
- 1977 Author R.S. Stelzer & R.N.Walters proposed "Estimating reversible pump-turbine characteristics".
- Nagrak - installed 1992 : This scheme was installed as part of the programme of German Technology Exchange (GTZ) in West Java, Indonesia. The pump is of Chinese manufacture, for which spare parts are easily available in the nearest large town. It is connected through a direct-drive coupling to an Indonesian-made induction motor as generator producing 4.5 kW

An example of a small PAT scheme used for energy recovery is at Barnacre, in the north-west of England. This uses a 30m (3 bar) pressure drop in the drinking water supply to Blackpool to generate 3.5 kW of electric power at a remote water treatment Pump as turbine schemes for slightly larger 'mini-hydro' plants have also been installed in Peru and Guatemala.

III. PRODUCT DESIGN AND SET-UP DEVELOPMENT

A. Modification in Pump

PAT (pump as turbine) is consists of different sub-parts which have the primary function to ensure the

rotation of the shaft and dynamometer at different heads, different flow rate and different load condition. The main component in sub-part of this are:

- I. Casing of Pump:- for inclosing the impeller of the PAT, we used the casing of the same pump that means, impeller and casing are the parts of same pump. But here we are using this for a reverse purpose
Outer radius = 25cm; inner radius= 18cm
Water inlet Diameter= 2.54 cm= 1 inch
- II. Impeller:- Impeller is acting as a blade of turbine which basically rotates as with radial flow of water come into it.
Diameter= 16cm; B= 0.7 cm
4 inlet blades with blade angle= 120 deg.
- III. Mounting: to mount the PAT properly we need to have a mounting which gives balance to the whole system. For this purpose also we brought the mounting of same pump.
- IV. Shaft: to transfer the rotational power to dynamometer one should use shaft. We also used shaft for same purpose and according to the requirement we had given proper radii and key hole into the shaft too.
Diameter of shaft at bearing= 28cm
Diameter at impeller = 20cm
Diameter at dynamometer= 20cm.
- V. Bearing:- For giving support to the shaft we had used two bearing which is interference fitted with mounting and shaft.
Two bearings of bearing number 6304.

B. Water Source

Water source is the primary requirement for this experimental set up. The main demand of this study involves availability of water source in which we can change head and flow rate conveniently. We used the source at fluid dynamics lab. Maximum Head generated by the source is of 40 m Maximum flow rate observe through this is around 3.2 kg/s

C. Guide Vane

The important study of this experimentation is to see the effect of guide vane on system like PAT. Guide Vane is placed inside the casing and in between casing and impeller so that it can guide the proper inlet water. Guide vane angle used for the purpose of experimentation is 20 degrees.

D. Dynamometer

Belt pulley Dynamometer is used in this experiment to impart load on PAT. We used different masses on this dynamometer so that we have a broad range of knowledge of our system. At one side of it, spring balance is used and at another side we have different weight.

Diameter of dynamo= 9.7 cm;
Spring balance zero error = 0;

Figure 2: Position of guide vane on the periphery of the casing

E. Gravimetric Flow meter

This is the device used to measure the mass flow rate of water entering into the PAT.

F. Pressure Gauge

This is again used to measure the head of the water coming into the PAT.

G. Tachometer

Tachometer is used to measure the rpm of the shaft, which is rotate because of the continuum flow of water into PAT.

IV. NON DIMENSIONAL ANALYSIS

A. Power No.

$$P = \rho N^3 D^5 \dots (iii)$$

The no. gives the extent of power generated by the turbine.

B. Discharge No.

$$q = Q / N D^3 \dots (iv)$$

The diameter of impeller exit is taken as the characteristic diameter.

C. Head No.

$$h = g H / N^2 D^2 \dots (v)$$

The head number is the main input energy parameter of the turbine. For every discharge number there is only one head number for a given turbine. Also the head number shares a unique relationship with discharge number for similar turbines over a wide range of conditions.

V. RESULTS

A. Without Guide Vanes

One of the results for the head of 8.5 m with different flow rate is given below in the table.

Head (m)	RPM	W ₁	W ₂	Mass flow (kg/s)	P _{in} (watts)	T (Nm)	ω (rad/s)	P _{out} (Watts)	η	Discharge no.	Head no.	Power no.
8.534	1512	0	0	1.75	146.05	0	158.56	0	0	0.41	3.70	0.00
8.534	1329	1	0.1	2.09	175.1	0.43	139.37	59.6174	34.05	0.56	4.78	0.91
8.534	1240	1.5	0.4	2.30	192.12	0.52	130.03	67.986	35.39	0.66	5.50	1.27
8.534	1194	2	0.5	2.43	203.17	0.71	125.21	89.269	43.94	0.72	5.93	1.88
8.534	1061	2.5	0.7	2.53	211.38	0.86	111.26	95.1904	45.03	0.84	7.51	2.85
8.534	980	3	0.9	2.59	216.3	1	102.77	102.577	47.42	0.93	8.80	3.90
8.534	723	3.5	1.1	2.63	219.9	1.14	75.819	86.4878	39.33	1.29	16.17	8.18

Figure 3: Experimental result of head number Vs discharge number

The head number-discharge number curve of the test turbine has followed the trend of actual turbine curves. Points corresponding to different head conditions all seem to lie within a broad curve. The degree of scatter i.e. deviation is insignificant.

Figure 4: Experimental result of power number Vs discharge number

The power number curves are almost identical. The curves for different heads are collapsing into one. Ideally for a turbine the power number curve should rise, reach a maximum point and then fall.

Figure 5: Experimental result of efficiency Vs discharge number

The curve is following the trend of actual turbine curves. But collapsibility characteristics are not very good.

B. With guide vanes

Figure 6: Experimental result of power number Vs discharge number

The power number curves are almost identical, except for H=6.1 (which is probably a mistake). The curves for different heads are collapsing into one for small discharge numbers but diverge with increase in discharge number.

Figure 7: Experimental result of efficiency Vs discharge number

The curve is following the trend of actual turbine curves. The collapsibility characteristics are much better in this case.

C. CFD Analysis of Guide vane

Geometry Creation: Firstly the CAD model of single guide vane with corresponding flow passage is made. The results obtained later than can be generalised for complete diffuser flow passage with guide vanes.

Figure 6: Wireframe diagram of the flow passage with single guide vane

Figure 8: Velocities Streamlines

Figure 9: Pressure Distribution

Observations: The results show that guide vane is not directing the flow as assumed on the contrary it's creating a hindrance to fluid flow. So it is recommended for future work to optimize the angle of vane through possible means.

VI. CONCLUSIONS

To sum it up in short, the characteristic curve for the pump running as turbine was drawn up through extensive testing and using data accumulated from the experiments. This gives us a better understanding of the optimal conditions for a pump running as turbine. The effect of guide vanes was studied and it has left us wiser as to how to best use the guide vanes for a pump of a given shape and dimension. The method of attaching guide vanes maybe used in future

for a simple and cost effective solution to the problem. The high efficiency--- close to 50% is an encouraging sign for the future use of this technology. Future testing maybe done taking various different guide vane angles. Also the variation of different sizes of impellers and casings needs to be studied.

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