Investigation of Centrifugal Pump as Turbine : A Review Report

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Abstract

Pump as turbine (PAT) is the best technique for satisfying the energy demands and providing the electrical energy in isolated and rural areas. Commercial development through renewable energy segment generates more employment and that leads to communal development of the country.

Due to the economic constraints the micro hydro left undeveloped. Still the running cost for micro hydro range are extremely low, the initial capital cost are high when compare with turbine cost. Currently, applications of pump as turbine have been involved in energy recovery systems such as water distribution systems, sewage systems, Reverse Osmosis systems, farm systems, irrigation systems, as pressure dropping valves and as small pump storage power stations. Since 1930, the main dispute was the selections of PAT for a micro hydro application. During the study, work done in the region of pump running as turbine in reverse operation has been clearly explained.

In the current review, the chronological improvement of PAT is studied. The technical report of the centrifugal pump running in turbine mode characteristics is presented. Theoretical, numerical and experimental investigations established by several researchers on PAT are reviewed. The existing trends and potential range for more development and implementation of PAT are also discussed.

Key words: *Centrifugal pump, Pump as Turbine, Renewable energy, Hydro power.*

1. Introduction

Energy plays a significant role in almost all areas of human and commercial activities, and it is particularly main input for those countries that are improving from financial point of view. The generation of electrical energy is essential to raise the economy's infrastructure of a country. Generation of power through the non-renewable energy source is quite familiar. Several thermal power plants are working all over the world for electrical energy generation but the rapid depleting environment and growing prices of petroleum products (coal, oil, gas, etc.) are the almost important complication in satisfying the power demands from these sources [1]. Electrical energy supply generated in world for about 20,053 TWh of installed capacity and that to hydro power contributes to around 16% in many countries it is the main source of power generation [2].

Economic growth through renewable energy creates more employment that leads to social improvement of the country. Almost promising non conventional energy for generating power in this condition is hydro machinery. Hydro power is a non conventional, non-polluting and environmentally being source of energy. The Ministry of Non-Conventional Energy Resources, Government of India recognized numerous sites in North India, generally in the Himalayan Range for the development of micro hydro power plants ranging from 15 to 50 kW [3].

2. Historical development of PAT

When the pumps were first used in turbine mode performance is uncertain [2]. In 1931, when [4] were trying to assess the complete characteristics of pumps, they accidentally realized that pumps could function very efficiently in the turbine mode. Later [5] published the absolute pump characteristics for a few pump designs based on experimental investigations. The further development of the technology of pumps-as-turbines, as well as its dissemination, has been inadvertently nurtured by the research on water-hammer in pumping stations and on pump-turbine schemes. This development of a low-cost technology made possible by the indirect benefits derived from R&D on advanced technologies is a pattern that can be observed in many other areas. In 1950s and 1960s, the

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model of pump storage power plants, in the range of 50–100 MW, was evolved mostly in urbanized countries to satisfy the peak power load. In later years, chemical industries became an additional area for the application of PATs for energy recovery system.

Even in water supply net works applications of this technology were found. This condition provides an effective phase of research and then beyond, standard manufactured pumps were calculated in turbine mode. In later years, many other techniques were developed by lots of researchers [6].

The expertise for the use of PAT for hydro power generation did not exist earlier. Though, advances in electrical equipment control technologies, rotary motion and torque have created the opportunity of the operation of pump rotating in reverse mode for power generation [7]. [8] many pumps were tested in turbine mode over the years and accomplished that when a pump operates in a turbine mode, its mechanical operation is smooth and quiet; its peak effectiveness is same as in pump mode.

3. Need of PAT for Hydro power generation

When the centrifugal pump works in reverse mode it simply reduce the equipment cost and can be used as an alternative to conventional turbine [1]. Pump manufactures do not generally provide the characteristic curves of their pumps in reverse action. Consequently, establishing a correlation enabling the passage from the "pump" characteristics to the "turbine" characteristics is the most important dispute in using a pump as a turbine. The hydraulic performance of a pump when rotates as a turbine will be changed. In general a pump will operate in turbine mode with higher head and discharge in the same rotational speed. Several researchers have offered some theoretical and experimental relations for predicting the PAT characteristics in the best efficiency point (BEP) [9].

Micro hydro power can be one of the most important alternative to isolated rural communities the advantages of electrification and the associated progress, as well as to improve the quality of life. It is one of the most commercial hydro power energy technologies for rural electrification in less developed countries [10].

The MNRE has renowned more than 6000 streams in north-east and north regions of India, that are not suitable for installation of large hydro power plants but are favourable for electricity generation in the range of 5–100kW. Mini, micro and small hydro power schemes can be installed on such water streams [6].

4. Pump running in turbine mode

Choice of correct specification pump to be used in turbine mode for a particular site in installation of PAT. For the commercial installation of PAT, it is essential to select proper category of pump. It is also required to predict its performance in turbine mode in advance before its installation. Many researchers have done lots of studies on these issues and proposed different correlations for the selection of pump which are summarized in this section.Range of suitable category of pump depends on discharge and head existing at the position,initial cost, maintenance cost, accessibility of pump **[11]** reported that all centrifugal pumps starting from low specific speed to high specific speed, single or multistage, axially or radially split, vertical or horizontal installations can be used in reverse approach.

The pump as turbine can be selected, based on range of head and flow through discharge, as shown in Fig.1 [12]. The axial flow pumps are suitable for high discharge and low head location,where in the case of multistage radial flow pumps are appropriate for low discharge and high head location.The range of 5-750 kW PAT selection was offered by [13]. The various parameter are involved in the selection of pump running in reverse mode such as operating range, head, pressure at the inlet and outlet zone, speed [11].

The feasibility of double suction pumps and in-line suction pumps in turbine form, when compare to pump mode the turbine mode are less efficient. Self-priming pumps cannot be used in turbine mode due to the existence of non-return valve and if the elimination of non return valve made the pump as PAT.

Dry-motor submersible pumps containing fin cooling arrangement for motor, are also not suitable for turbine mode operation due to over heating issue [14]. Pump works as turbine mode economically in the range of head from 13–75 m.

Due to increase in head range the cost per kW decreases. The operational principles of single stage end suction centrifugal pump in pump and turbine modes are shown in Fig.2 [15]. It can be seen that, in turbine mode flow direction is reversed as compared to pump mode.

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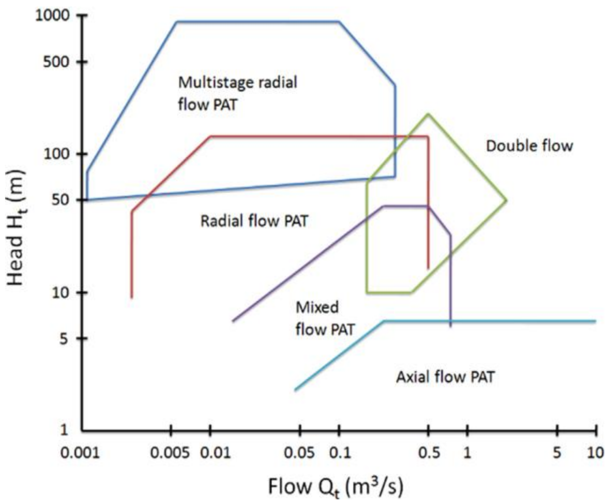

Figure 1. Different pumps suitable as turbines.

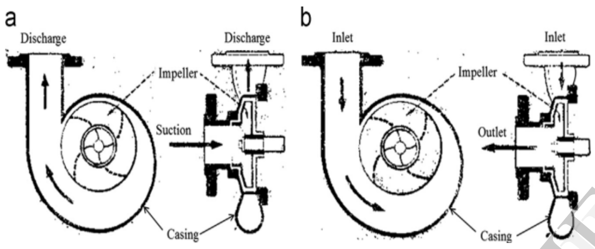

Figure 2. Centrifugal pump in (a) pump and (b)turbine modes

Applications of PAT

The application of PAT is best alternative to small, mini and micro hydro power and it is also used very efficiently in the energy recovery systems such as water distribution systems, sewage systems, Reverse Osmosis systems, farm systems, irrigation systems, as pressure dropping valves and as small pump storage power stations.In the Reverse Osmosis systems more than 75% of hydraulic energy is not used for beneficial purpose [16].

In Hydraulic Power Recovery Turbine (HPRT) systems,centrifugal pump were used to increase the overall efficiency of system. For the irrigation systems method of pump running as turbine mode was developed by [17]. [18] PAT as first-class option to utilize the surplus existing energy in natural falls, irrigation systems, water distribution system, sewage or rain systems. [19] PAT used as pressure reducing valve (PRV) in drinking pipe systems.[20] the method of energy recuperation by using PAT instead of PRVs in the water distribution system.[21] designed a process of a 97 kW micro hydro system for Roman Bay Sea Farm in Gansbaai in the Western Cape Province of South Africa.

5. Review of Literature

Theoretical Investigations on PAT

Williams [22] investigated different forms of prediction methods for the effective use of PAT.The experimental study were conducted for more than 30 pumps of different standards and suction methods.The result of the particular study clearly provide that no method will be suitable for the prediction of generalised PAT. Yang et al., [9] investigated the insufficient understanding of the correlation between pump and pump as turbine (PAT) performance is a major problem encountered in the PAT selection and design. Therefore, establishment of accurate PAT performance prediction methods is necessary.

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Singh and Nestmann [23] developed an efficient model to study the rounding of the sharp edges at the impeller edge on a combination of radial flow and mixed flow pumps as turbines using experimental parameter. Proper rounding of impeller selection provide optimistic answer to the overall efficiency in all operating condition.

Derakhshan et al., [24] derived a latest technique to forecast the BEP of a PAT based on pump‘s hydraulic specifications.A process was also existing for selecting a appropriate pump to function as a turbine in a micro hydro-site. Derakhshan and Nourbakhsh, [25] calculated the ‘area ratio’ method for best efficiency point in theoretical investigation.Each and every part of pump were estimated by geometric parameter and through performance curves.

Numerical Investigations on PAT

Rodrigues et al., [26] worked on computational fluid dynamics to know about the flow conditions and hydraulic performance of PAT.The numerical study is focused on the casing of pump, inlet and outlet zone ,impeller diameter and draft tube. CFD provides valuable result when compared with experimental result with some error ranging upto 10% for different part load conditions.

Natanasabapathi and Kshirsagar [27] investigated PAT using CFD approach.It was concluded that the impractical consequences can be obtained from amorphous griding across the interface between stationary and revolving structure. Thus, structured griding close to the interface is a resolution to minimize such errors in the results.

Rawal and Kshirsagar [6] carried out numerical analysis on axial type pump running in turbine mode. Resemblance was established between the numerical and experimental outcome for best efficiency point. The numerical system was quite supportive in study of different parameters like losses in the impeller, casing , draft tube and flow pattern which could not be calculated through experiments.

Derakhshan and Nourbakhsh [25] A centrifugal pump (NS = 23.5 (m, m3/s)) was simulated using CFD in direct and reverse modes. To verify numerical results, simulated pump was tested as a turbine in the test rig. Characteristics of best efficiency point predicted by numerical methods were not in good coincidence with experimental data. Future works on CFD application can be improved, since the application of CFD fails in the turbine boundary as proved with this study.

Nautiyal et al., [28] study on the application of numerical methods and its restrictions. Investigation reported that CFD study was an efficient design tool for predicting the performance of centrifugal pumps in turbine mode and to identify the losses in turbo components like impeller,draft tube and casing.

Barrio et al., [29] worked out a numerical analysis on the uneven flow in commercial centrifugal pump working in forward and reverse direction mode with the help of CFD tool . Outcome of mathematical simulation were in good agreement with the experimental results. The study clearly explains that in the reverse mode, the flow corresponding to the impeller geometry at normal conditions while developing re-circulating fluid regions at high and low flow rates.

Fecarotta et al., [30] studied the least difficulty of the CFD computation mesh to perform faster and consistent simulations. The investigation described the CFD study as reliable tool to better understand the interaction between the hydro mechanical components and the flow performance in spite of complex computation. CFD calculations were carried out to forecast the turbine performance under various flow conditions and the characteristic curves for pump and turbine modes were obtained.

Agarwal [31] noted computational Fluid Dynamics (CFD) is an efficient design tool for predicting the performance of centrifugal pumps operating in turbine mode. It has been established that the results from numerical and experimental investigation do not match exactly in case of PAT. It is recommended that the variation can be minimized through development in computational study by using finer mesh, numerical methods and turbulences models. CFD study is helpful in identifying the losses in hydraulic machine components like impeller, casing, draft tube.

Experimental Investigations on PAT

Chapallaz et al., [12] investigated on conversion factors of PAT. Based on the specific speed of pumps, conversion factors graphs were developed. The conversion factors obtained from the graphs were set up to be within satisfactory limits even for the points far away from best efficiency point.

Fernandez et al.,[7] explained the performance of a centrifugal pump in turbine mode at different revolving speeds with the help of experimental analysis in a hydraulic arrangement. The results showed that the turbine behaviour can be predicted to some extent from the pump behaviour and the performance curves were also obtained for PAT working at same speed and head.

Joshi et al., [32] considered a easy approach to forecast PAT performance with a case study of a micro hydro location producing 25kW electric power from 5.5 meters of gross head. Then formulated a correlation between turbine and pump specific speeds to aid in pump selection for a particular hydro site.

Derakhshan and Nourbakhsh [33] offered some correlations to calculate the best efficiency point of a PAT based on pump hydraulic description using the experimental data. Four centrifugal pumps of industrial type with specific speeds from 14 to 56 (m,m3/s) were tested experimentally. The pumps with high specific speed needs lower ratios of discharge and head (for higher operating efficiency). But difference in power ratio were not relative to variations of pump‘s specific speed.

Suarda [34] studied an experimental investigation by means of two small pumps to find out performances of pumps in turbine. It was accomplished that centrifugal pumps as hydro turbine was a more possible alternative solution.

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Singh and Nestmann [35] investigated experimental study on three pumps with specific speeds of 18.2, 19.7 and 44.7. The prediction errors in the pump head at the maximum load position were significantly reduced, particularly for the lower specific speed PAT.

Nautiyal et al., [36] carried out an experimental analysis on a centrifugal pump having specific speed as 18. The best efficiency in turbine mode was set up to 8.53% inferior than best efficiency in pump mode. The experimental outcome of tested pump and other pumps were used to expand new correlations to attain turbine mode uniqueness of pump from pump mode characteristics by using their best efficiency point and specific speed in pump mode. Values obtained from the derived correlations were compared with experimental results and results of other methods which showed very less deviation.

Experiments on PAT having specific speed range from 10 to 300 and developed a monogram to aid in the selection of a pump to be used as turbine for a particular site. This reduced the computation effort concerned in the choice of PAT [31].

Experimental and numerical investigation into impeller trimming to the influence of pump as turbine were carried out on a single stage centrifugal PAT. An open PAT test rig was built in laboratory; a single stage centrifugal PAT with original impeller and impeller after once and twice trims was tested. The results in both turbine and pump modes are presented. Experimental results show that PAT's flow rate at the BEP shifts from 95.23 m3/h to 86.14 m3/h and then moves back to 93.63 m3/h, its efficiency at the BEP is dropped by 4.11% as impeller is cut from 255 mm to 215 mm. PAT's Q–H curve becomes steep and Q–Pshaft curve moves almost parallel down [37].

End suction centrifugal pump (CALGON) type of 15.36 (m, m3/s) specific speed was experimentally tested to study the pump working in turbine mode characteristic. The experiment work showed that a centrifugal pump can acceptably be functioned as turbine without any mechanical problems. Compared to pump action, the pump operates at higher discharge and heads values in turbine mode. The BEP in turbine mode was found to be lower than BEP in pump mode. In the tested pump the BEP was only 39.0 % in turbine mode was with flow and head of 13.52 l/s and 30m respectively [38].

6. Conclusion

The review of the current study will provide complete details for selection of centrifugal pump as turbine for micro-hydropower plants. The future work for further development of PAT performance will be on low cost modifications in the impeller particularly in impeller diameter, blade wrap angle, impeller inlet width, blade inlet angle, impeller flow inlet zone, outlet zone, fluid structure interaction, casing quality, impeller eye clearance, bearing quality, selection of material for shaft and impeller. Characteristics of best efficiency point can be improved by using various modification recommended by earlier researchers and further implementation of computational fluid dynamics (CFD) will provide enhanced understanding of PAT.

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