International Journal of Engineering and Advanced Research Technology (IJEART)
ISSN: 2454-9290, Volume-3, Issue-9, September 2017

Design and Optimization of a Pump as Ecofriendly Hydraulic Turbine by Using Ansys

Rajesh kumar Verma, Mukesh Kumar Verma, Devvrat Verma

Abstract— **Energy plays an important role in almost all areas of human and commercial activities. Electricity generation through the non-renewable sources is quite common to meet the demand of the growing population and developing world. But the non-renewable energy sources are not expedient from ecological point of view and also responsible for producing major greenhouse gas (GHG) and promote global warming. These impediments forces to look for other clean and cheap sources for energy generation. The current concern on the global environment has imposed restraints on the production of electricity. The emphasis is put on the development of environmental friendly methods to promote the sustainable social development. It is in these circumstances, that micro hydro power is drawing more attention.**

The deployment of these technologies not only contributes to a significant percentage of carbon dioxide emission reduction, but also aids to reduce energy consumption and mitigate environmental impact. The need for such eco-friendly technologies in buildings has underpinned significant increases in the application of wind-driven ventilation techniques. This includes turbine ventilator, a wind-driven ventilation device or air extractor that is commonly used in attic, rooftop spaces or loft to facilitate ventilation, control high energy consumption, and improve indoor environment. In order to gain a deeper understanding into existing knowledge in this field, this paper discusses low carbon technology concept and characteristics of turbine ventilator. Furthermore, physical and operating parameters that influence its performance are also discussed.

This study focuses on the technical, theoretical and financial analysis of a hydro power plant, which is considered as dependable and sustainable among all other forms of renewable energy. Hydropower energy is broadly used all over the world, whether in the form of mini hydro for a single village or a massive dam to serve the entire country. Industrialized countries have utilized their hydro potential extensively.

Under the present investigation, performance analysis of a commercial centrifugal pump provided with movable guide vanes to improve part load efficiency in turbine mode has been carried out using Computational Fluid Dynamic. Complete model for simulation was prepared using Pro-E 2.0 and mesh was generated using ANSYS 'MESH'. Simulation was carried out for different guide vanes positions using ANSYS 'FLUENT'. Operating characteristics for modified good agreement has been found between the numerical and experimental results.

Index Terms— **Turbine, Pump, Ansys, Casing, Impeller, Runner Speed, Energy**

I. INTRODUCTION

Williams [1] presented three examples of different types of PAT schemes of micro hydro power and advocating the use of induction generator and controller (IGC) design of PAT units for isolated micro-hydropower projects. The study illustrated many advantages by using PAT with induction generator. Single-phase induction motors can be used as stand-alone generators, but there may be problems in achieving excitation and in determining the size and arrangement of the capacitors required. However, the use of three-phase induction motor as a single phase generator is a good approach of providing a single-phase supply. This paper described range of PAT which covered the range of multi-jet Pelton turbines, cross flow turbines and small Francis turbines with the advantages of both practical and cost advantages over other types of turbine for medium head sites.

Derakhshan et al. [2] redesigned shapes of the blades using a gradient based optimization method involving incomplete sensitivities for radial turbo machinery developed by **Derakhshan et al.** to obtain higher efficiency. The optimization was performed in two steps. The primal optimization results show that the torque, head and hydraulic efficiency was increased by 4.25%, 1.97%, and 2.2%, respectively and for final optimization these values was improved by 2.27%, 1.08%, and 1.17% respectively.

Derakhshan and Nourbakhsh [3] reported a theoretical analysis to calculate best efficiency point of an industrial centrifugal pump running as turbine based on ''area ratio" .In this method, turbine mode hydraulic components of pump were estimated by using geometric and hydraulic characteristics of pump in pumping mode. Hydraulic losses in volute and impeller, mechanical losses related to power losses, volumetric losses were taken into account to calculate the head, discharge and efficiency of PAT at BEP. Theoretical method predicted 1.1%, 4.7%, 5.25% and 2.1% lower discharge number, head number, power number and efficiency than experimental data at BEP, respectively. The derivation for finding out the relations for BEP of PAT was described in details in the paper. The final relation for turbine maximum efficiency is expressed as

$$\eta_t = \frac{P_{nt}}{\gamma \, Q_t H_t} = \frac{\gamma Q_t H_t - P_{vt} - P_{lt} - P_{et} - P_{it} - P_{mt}}{\gamma Q_t H_t}$$

Joshi et al. [4] explained the simple stand alone micro-hydro scheme which can be applicable to remote communities. A simple method for the prediction of PAT performance to aid in pump selection was described with help of case study of low head micro-hydro site, consisting of an unregulated PAT directly coupled to SEIG (self-excited induction generator) connected to local loads through inverter-distribution transformer. Using complete pump characteristics with different specific speeds by **Swanson [5]**, PAT to pump operating ratios in a constant head mode were developed. After finding out the operating ratios corresponding to the specific speed of pump, required pump for the project is selected. After this, steady state analysis of a SEIG driven by an unregulated PAT was simulated using **Chan's approach**

[6]. Variation in different quantities i.e. speed frequency, output power and efficiency with load variation was simulated. Also variation in generated voltage with excitation capacitance was done.

Derakhshan and Nourbakhsh [7] derived a new method to predict the BEP of a PAT based on pump's hydraulic specifications. Some correlations for low specific speed pumps ($N_s < 60$) were developed with same specific speeds and having different impeller's diameters. The value of h and q were predicted by this method which are in good coincidence with experimental data but more experimental data will improve accuracy of this method. Authors have also been discussed a comparison between the predicted values of h and q by different methods for finding out the BEP of PAT. But no single method was in closely coincidence with the experimental data throughout the whole range of specific speeds. A procedure was presented in this study to select a proper centrifugal PAT for a small hydro-site (only valid for specific speed≤ 150 (turbine)).

Ramos and Borga [8] carried out steady and transient regimes analysis based on suter parameters. This study intends to be a pragmatic tool for better understanding about the use of pumps in turbine mode. This analysis gave a more economic solution to recover part of dissipated energy, in point of view of reduced dimensions imposed for turbo-machine equipment. The study illustrated an advantageous solution of pumps in drinking water or sewage systems for recovering power. After analysis, it is concluded that the use of pumps as turbines can obtain a maximum relative efficiency up to 80%, depending on the type of the runner

II. PROBLEM IDENTIFICATION

A general review of the present status of design principles which apply equally to centrifugal pumps and hydraulic turbines. In project first develops step by step the fundamental ideas under lying the theoretical behavior of a runner having an in finitely large number of thin blades which guide the fluid perfectly. The resemblance between the blading ordinarily used and the wing of an airplane has led to analysis on the basis that each blade acts as an airfoil. In the project points out the many limitations of this theory and advocates a new beginning, taking as a starting point the theoretically perfect runner. By decreasing the number of blades first from infinity to a finite but very large number, I analyze the forces and influences that are at work. Although he does not claim to have arrived at a final solution , I demonstrates the play of one effect upon another , and suggests that further experimentation should assist in making proper allowances for the uncertainties not subject to strict analysis and which become more and more important as the number of blades is reduced . The final section deals with the best conditions for the design of high speed runners. The influence of the principal figures of lay out upon which both efficiency and cavitations are dependent are discussed ,and complete curves for efficiency and cavitations coefficient are given for three different specific speeds. This speed is defined by the same figure for pumps and turbines. He feels that both theories in spite of their defects can be used to advantage as experimental knowledge is progressively increased, and demonstrates that mathematics will throw light on a number of vital problems dealing particularly with efficiency and cavitations . He suggests for consideration a special type of profile, and expresses the hop e that by combining the laboratory with theory, it will be possible to realize improvements in existing equipment, and finally to build up a strict method for pump and turbine design meeting properly and satisfactionarily all of the requirements for high specific speed and small number of blades.

III. MODELING AND NUMERICAL SIMULATION

The basic elements of the modified pump used in turbine mode are casing, impeller, guide vanes and draft tube. The computational modeling and meshing of calculation domain is first step in CFD analysis. For modeling purpose, design details of centrifugal pump have been carried out in last chapter. The complete process of computational modeling and meshing of pump configuration i.e. the impeller, casing and the draft tube and guide vanes is described in following paragraphs. After meshing, flow simulations are carried out for different flow rates and operating characteristics of modified PAT is obtained and compared with available with available experimental results. The salient features of centrifugal pump are given in Table.

TABLE 1

S.No.	PARTICULARS	DIMENSIONS
1.	No. of impeller vanes	7 Nos.
2.	Diameter of impeller eye	150 mm
3.	Outer diameter of impeller	260 mm
4.	Blade thickness	6 mm
5.	Width of impeller at outlet	25 mm
6.	Vane angle at inlet	12.5^0
7.	Vane angle at outlet	37^0
8.	Rated Head	21.5 m
9.	Rated Discharge	42.5 lps
10.	Rated pump efficiency	78 %
11.	Rated Speed	1500 rpm

IV. CREATING MODEL OF IMPELLER

Impeller of pump is both side covered and contain seven radial curved blades. The detail of impeller of centrifugal pump has been calculated for modeling. Creation of Impeller model is carried in two steps: creation of blade profile and creation of complete runner domain. Blade profile is created using Blade Gen software of ANSYS 14.0. Steps for creation of impeller are given below:

- Select radial impeller for centrifugal pump then a dialog box as shown in Fig 1 will open.
- Input for blade profile will be given. After adjusting vane angle at inlet and outlet, Meridional Profile of blade is shown in Fig

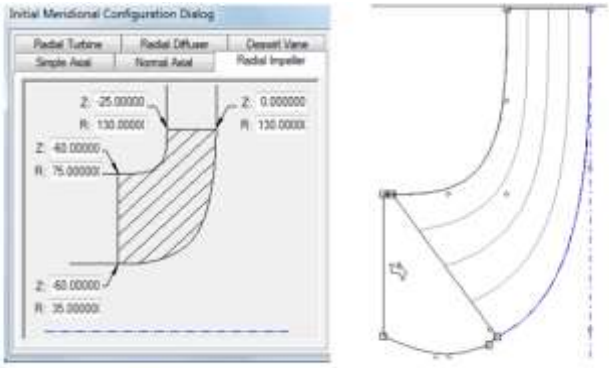

FIG 1

- This blade profile is transferred to Geometry.
- This blade profile will be opened in Geometry and save IGES format of blade profile and open in Pro-Engineer as shown in fig.
- After this, all the domain of complete runner will be created in Pro-E by using simple commands like extrude and revolve.

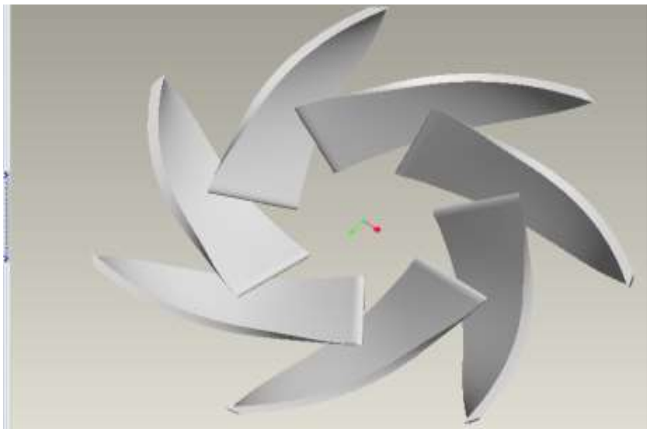

Fig. 2 IGES format of blade profile in Pro-E

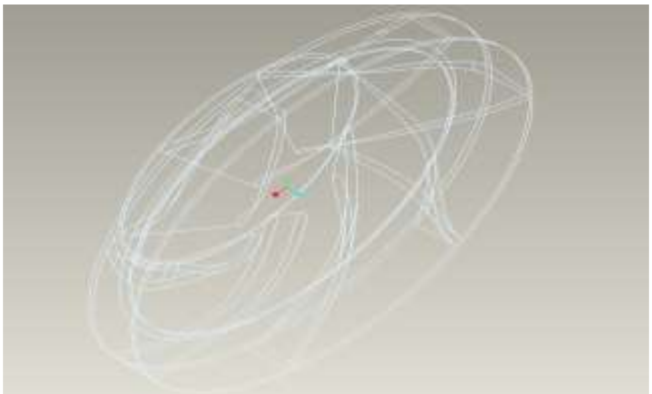

Fig. 3 Wireframe of complete model of impeller in Pro-E

V. NUMERICAL SIMULATION OF FLOW FIELD IN PUMP AS TURBINE

The performance of modified PAT can be well understood by numerical simulation of flow field inside the modified pump as turbine. The simulations are made at constant speed of impeller at 1500 rpm and at different values position of guide vanes for different discharge. Range of parameters which have been considered for simulation, are given in Table 2 for the pump used as turbine after modification.

Table 2

S. No.	Parameters	Range for modified PAT
1.	Head (m)	6.0-25
2.	Discharge (lps)	22.00-53.00
3.	Pump speed (rpm)	1500 rpm

To carry out the flow simulation on modified PAT, set of boundary conditions has been specified i.e. mass flow inlet at casing inlet and pressure outlet at draft tube outlet.

Overall efficiency of modified PAT is calculated based on the fundamental equation, i.e. ratio of output power from the turbine to input power supplied to the turbine [60].

$$\eta = \frac{T\omega}{Q\,(p_1 - p_2)} \qquad (2)$$

In above equation, T is the net torque acting on the runner (N-m), ω is the angular speech (radian), Q is discharge through PAT (m^3/s), p_1 is total pressure at the inlet to the casing (Pa) and p_2 is the total pressure at the exit of draft tube (Pa). The net torque acting on the runner is a resultant of pressure and viscous moments and is calculated by taking surface integral of cross product of stress tensor and radius vector.

$$T = \left(\int \left(\vec{r} \times (\bar{\bar{\tau}} \times \hat{n}) \right) d_s \right) . \hat{a} \qquad (3)$$

Where S represents the surfaces comprising all rotating parts; τ is the total stress tensor. $\hat{n}$ is unit vector normal to the surface, r is the position vector, $\hat{a}$ is a unit vector parallel to the axis of rotation.

VI. PRESSURE CONTOURS AND VELOCITY CONTOURS AT DESIGN CONDITION

Variation of pressure and velocity for a particular mass flow rate (Q= 46 lps design condition) at inlet and pressure at draft tube outlet in different parts inside the modified PAT provided with guide vanes are shown by different colors. With the help of pressure contours generated in 'FLUENT', Low pressure zone inside the modified pump as turbine can be determined which are useful to identify cavitations zones inside the modified PAT. To avoid the cavitation inside the modified PAT, pressure at any point within the PAT component should be higher than vapor pressure (10.302×10^4 N/ m^2). The variations of pressure distribution inside the different component are shown in Fig. 4 to Fig. 8.

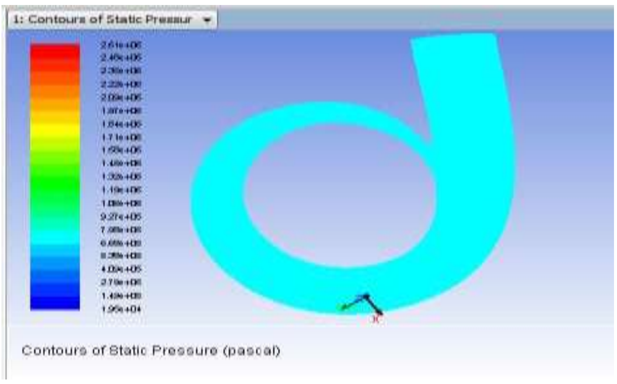

Fig. 4 Variations of pressure distribution inside the casing

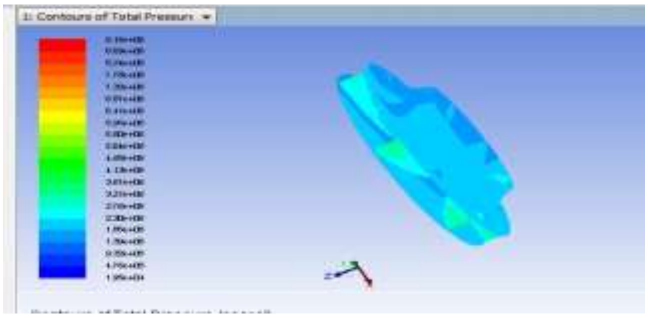

Fig. 5 Variations of total pressure distribution inside the impeller

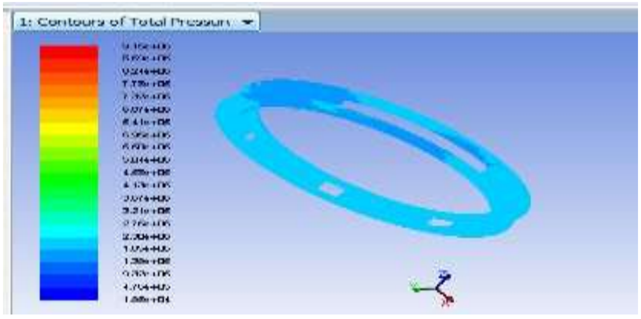

Fig. 6 Variations of total pressure distribution inside the guide vanes

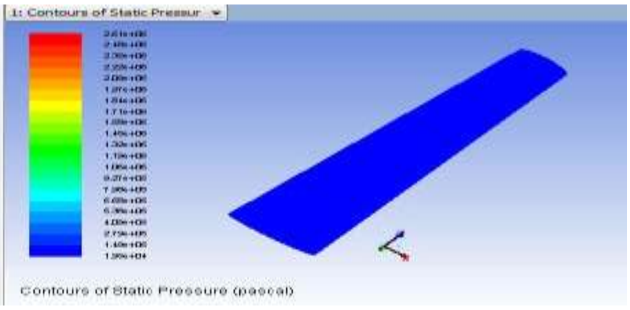

Fig. 7 Variations of total pressure distribution inside the draft tube

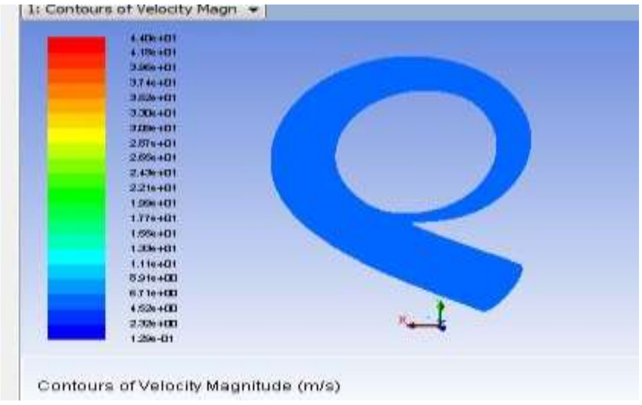

Fig. 8 Velocity in casing

VII. COMPARISON OF CFD RESULTS WITH EXPERIMENTAL RESULTS

We carried out experimental investigation on PAT provided with guide vane around the impeller. Table 3 shows the experimental results of previous study. An attempt has been made to compare the CFD results with these available experimental results. Fig 9 shows the comparison between experimental and CFD results.

Table 3: Available experimental results

S. No.	Flow (lps)	Power input (kW)	Power output (kW)	Efficiency (p.u.)
1	22.16	1.45	0	0
2	23.37	1.56	0.2	0.11
3	29.71	2.2	0.8	0.4
4	33.05	3.05	1.3	0.51
5	39.32	6.01	3.2	0.63
6	42.94	6.99	3.9	0.65
7	46	9.12	5	0.65
8	47.6	9.61	5.1	0.64
9	48.9	10.15	5.2	0.62
10	49.26	11.14	5.3	0.6
11	51	11.74	5.5	0.57

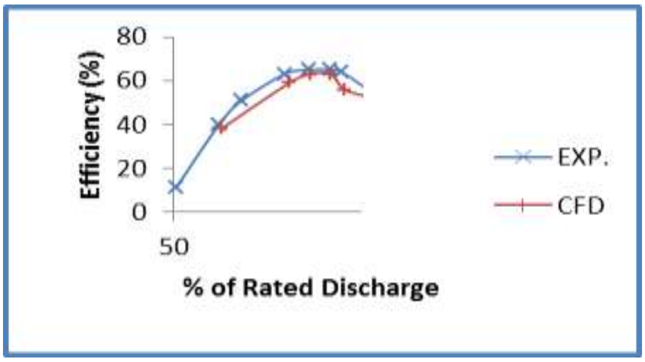

Fig. 9 Comparison of experimental and CFD results for modified PAT provided with movable guide vanes

Results obtain from the CFD analysis of Pump as Turbine (PAT) shows satisfactory agreement with the available experimental results. The average percentage deviation of 6.42 was observed. Reason for deviation in results can be errors in geometry creation due to complex geometry of impeller and casing and also due to quality of mesh in impeller. Thus, it can be concluded that the truncation error, round-off error, modeling error, poor quality mesh and some ideal assumptions like steady state flow, neglecting friction losses, boundary layer effect etc. are the causes of deviation between CFD results.

VIII. CONCLUSIONS

It is well known that turbines used at such micro hydro sites can easily be replaced by PAT with a number of advantages except the disadvantage of having poor part load efficiency due to absence of flow regulating mechanism in it. Therefore in order to eliminate PAT's disadvantage the centrifugal pump has been modified by providing movable guide vanes around its impeller. In this dissertation, an attempt has been made to analyze the performance of modified PAT provided with movable guide vanes using CFD technique. Following conclusions has been made from the present work of dissertation:

i. A centrifugal pump of mixed flow type having specifications as; head: 21.5 m, discharge: 42.5 lps, speed: 1500 rpm has been selected for the present investigation.

ii. Detailed dimensioning of impeller and casing for modeling purpose has been carried out. Since Draft tube is an important part for turbine operation, so the design parameters for draft tube have also been computed. Guide vanes design parameters are taken from the previous study .

iii. Modeling for modified PAT has been done using the software PRO-E 2.0.

iv. Flow simulation on the modified PAT has been carried out using the software ANSYS 'FLUENT'. Results for different flow rates at different guide vanes angles have been obtained.

v. The operating range of pump as turbine has been obtained at maximum part load efficiency around 63% after modifications.

vi. Operating characteristics curve have been drawn from CFD results and are compared with experimental results. It has been observed that numerical results are found to be lower than experimental results. This may be due to truncation error, round-off error, modeling error and some ideal assumptions.

REFERENCES

[1] http://www.nrel.gov/docs/fy01osti/29065.pdf.
[2] IEEE Guide for Control of Small Hydroelectric Power Plants, March 10, 1988.
[3] CEA, "Guidelines for development of Small Hydro Electric schemes", Govt. of India, New Delhi, 1982.
[4] http:/www.eren.doe.gov/factsheets/hydropower.html. White, F.M. (1994), Fluid Mechanics, (3rd edition), McGraw-Hill, New York.
[5] Doeblin, E. O.: Measurement Systems. Application and Design. McGraw-Hill Book Company, New York, 1986. ISBN 0-07-017336-2.
[6] Robert.J., Knolwlton, Peter W.Ludewig, Jack C., and Phillips John H., "Turbine Performance Test at the Robert Moses Niagara Power Plant", New York, Water Power ,1997.
[7] Richard.Jr., Voith, Woods, J.L, and Gulliver, J.S., "Field Efficiency Testing of Hydro Electric Turbines", USA, Water Power, 1989.
[8] Lal, Jadish, "Hydraulic Machines", Sixteenth Edition, 1993.
[9] Brown, J.G.,"Hydro-Electric Engineering practice", Blackie, 1989.
[10] Francis, J.R.D.," A Text Book of Fluid Mechanics", Arnold Press, 1982.
[11] JACK LEWIN,"Hydraulic Gates and Valves", published by Thomas Telford, London first edition, 1995.
[12] HCI publication, "The Guide to Hydro Power Mechanical Design", USA, 1996.
[13] http:/www.tam.uiuc.edu/courses/TAM235/Lab_manual/S.pdf Munson, B.R., D.F Young, and T.H. Okiishi.(1998),"Fundamentals of Fluid Mechanics",3rd edition, New York: Willey.
[14] Modi, P.N., Seth, S.M., "Hydraulic and Fluid Mechanics", Eleventh Edition, New Delhi, 1995.
[15] IEC Publication 41, "International Code for Field Acceptance Test of Hydraulic Turbines", International Electro-Technical Commission, Geneva, Switzerland, Current Version.
[16] HCL Publication "Guide to Hydropower Mechanical design", USA 1997

Rajesh kumar Verma, M Tech Student, VITS Jabalpur (MP.)
Mukesh Kumar Verma, M Tech Student, VITS Jabalpur (MP.)
Devvrat Verma, M Tech Student, VITS Jabalpur (MP.)