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Review Article

Review of various Aspects of using Centrifugal Pump in Turbine Mode for Small Hydro Power Generation

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Abstract

In current scenario Per capita energy consumption of any country is one of the prime index to assess social and economic development of society. From ancient time we human being has been searching such a incredible source of energy which can fulfill our daily energy demand without damaging our ecosystem such that faster, sustainable and more inclusive development of society can be ensure. In developing country like India to provide daily energy required to remote areas is yet a big challenge but availability of low head water stream can be good alternative to install micro hydropower plant to convert water energy into electricity. Power producing range of micro hydro plant is 5KW to 100KW but capital cost of small turbines is a big constraint to install such a plant by local community or formers who live in remote and hilly area. Use of Centrifugal pump in turbine mode (PAT) can be a better option to reduce capital as well as maintenance cost of plant. In current study different small turbine suitable for micro hydro power plant are discussed and their performance comparison with PAT are made. Here different types of centrifugal pump casing to be run in turbine mode are presented. Theoretical, Experimental, numerical and computational (CFD) analysis performed by different researchers are reviewed. This paper covers information of identified potential and step taken by MNRE (INDIA) to encourage them.

Keywords: *Pump as turbine-PAT, Centrifugal pump-CFP, Computational fluid dynamics-CFD, small hydro plant-SHP, micro hydro plant-MHP, Pico hydro plant-PHP, best efficiency point-BEP.*

1. Introduction

Micro hydro power (MHP) plant is type of renewable and hydro power plant that produces electricity up to 100KW by using potential energy of low head(below 6 meter) water stream (www.mnes.nic.in). Micro hydro plants are mostly used in developing country to supply required electricity to isolated homes or community in remote areas where main power grid supply is not available. According to ministry of new and renewable energy sources(MNRE)in north and northeastern part of India more than 6000 low head water stream are available on which low head turbine can be installed to generate electricity (https://energypedia.info/wiki/). Now a day there are environmental, economic and public restraints to install large hydroelectric power plant then micro hydro plant are prominent alternative to produce green energy at low cost more ever by using pump in turbine mode is cheaper way to reduce high capital cost of small hydro turbines. The outstanding advantage of PAT is Availability of wide range of Pumps at standard size, low erection, operation and maintenance cost. According to Williams using PAT for SHP/MHP is practical and economic advantage over low heads turbines. To predict the performance of pump in turbine mode accurately is basic problem but now different methods are available. Cric Greacen told that lack of performance data of PAT is basic constraint in wider use of PAT.

2. Energy scenario of India

India is blessed with different type of energy resources like fossils fuels, Hydro energy, Nuclear energy and many other form of Renewable energy etc. According to ministry of power (http://powermin.nic.in/power-sector-glance-all-india) total installed power generation capacity as on 31-03-2016 is 298060 MW in the Country and sector wise energy generation are as

Table 1 sector wise energy generation in India

Name		Generation (mw)
Thermal	Coal	185,173
	Gas	24,509
	Oil	994
	Total	210,675
Hydro(renewable)		42,783
Res (MNRE)		38,882
Nuclear		5780
Total		298,060

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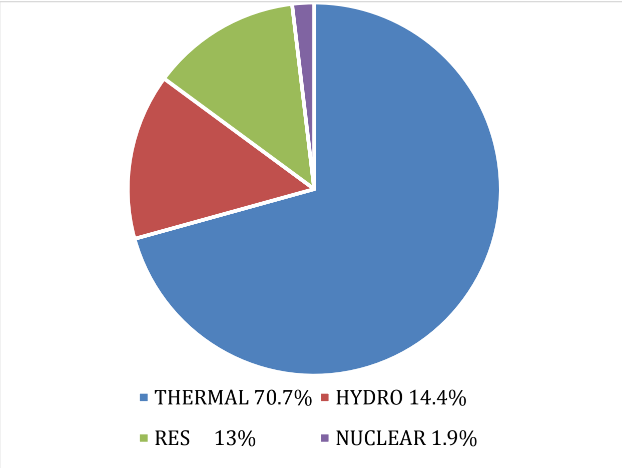

Chart 1 Percentage wise sectorial electricity generation

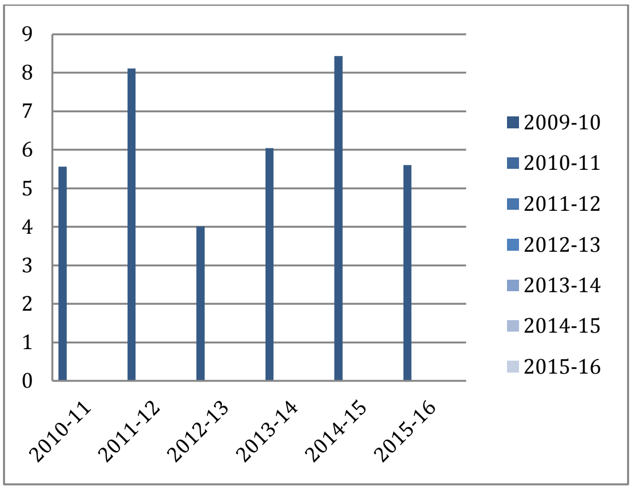

Chart 2 Energy generation growth in %

3. Hydro-energy scenario of india

India is blessed with enormous hydro-electric potential which is assessed to be about 148,701MW (http://www.cea.nic.in/reports/monthly/hydro/2016 /hydro potential region-02.pdf) but installed hydro power generating capacity is 42783 MW (http://www.cea.nic.in/reports/monthly/installedcap acity/2016/installed_capacity-03.pdf) till 31 march 2016. India secures 5thglobal rank in term of exploitable hydro potential and 7th global rank in term of installed hydro potential (http://www.bp.com/ content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf).

In addition to this 20000 MW small hydro potential is estimated but installed small hydro potential is 4273.9 MW only (http://mnre.gov.in/mission & vision2/achievements). Ministry of new and renewable energy is responsible to develop small hydro plant (SHP), which further classified SHP (http://mnre.gov.in/schemes/grid-connected/small-hydro).

Table 2 Type small hydro plant

Scale	Station capacity (kw)
Micro hydro	Up to 100
Mini hydro	101-2000
Small hydro	2001-25000

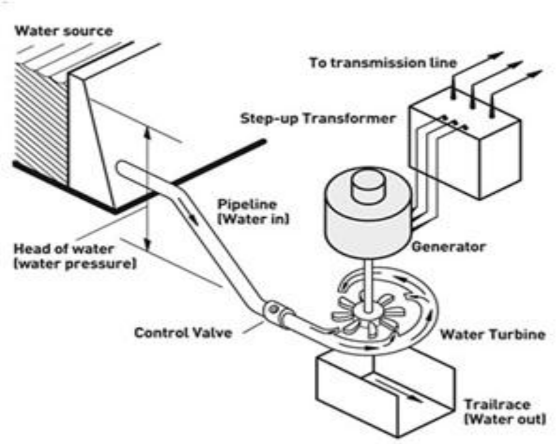

Figure 1 Schematic view of hydro power plant parts

(https://www.google.co.in/search?q=photo+of+micro+hydro+plant &espv=2&biw=1920&bih=971&tbm=isch&tbo=u&sourceuniv&sa=X &ved=0ahUKEwiPnKT9vMzMAhXDTo4KHZprDXoQ7AkILw#imgrc= NYtflSoV_NG92M%3A)

Figure 2 Schematic view of MHP Site

(https://www.google.co.in/search?q=photo+of+micro+hydro+plant &espv=2&biw=1920&bih=971&tbm=isch&tbo=u&source=uv&sa=X& ved=0ahUKEwiPnKT9vMAhXDTo4KHZprDXoQ7AkILw#imgrc=T6jfG SGZWejpwM%3A)

In India micro hydro plant (MHP) can be great source of energy to boost electrical supply to remote and hilly villages or community. To promote MHP, MNRE is providing technical and financial assistance to organization or individual as per its guidelines. In Himalayas and north-east India many sites are there where MHP can be installed. In the State of Uttarakhand, Uttarakhand state renewable energy development agency (UREDA) has constructed 44 MHP with installed capacity 4.29 MW and 19 MHP with capacity 2.315 MW are under implementation. Due to these MHP more than 300 villages & hamlets have been electrified through these projects the state. MHP sites& estimated capacity in Uttarakhand (http:// www.ureda.uk.gov.in/ pages/display/131-micro-hydro-projects) are listed below.

Table 3 Commissioned MHP in Uttarakhand

District	No of site	Capacity(kw)	Electrified	
			No of villages	
Bageshwar	21	1495	55	103
Chamoli	11	1125	41	18
Uttarkashi	4	570	6 & Ganotri Dham	13
Rudraprayag	1	100	Kedarnath Dham	
Pithoragarh	3	600	27	4 & Grid Feed
Nanital	1	100	5	Grid feed
Puri	1	100	Grid feed	
Tehri	1	100	3	
Almora	1	100	3	
Total	44	4290		

Table 4 Under construction MHP (till May 2014) in Uttarakhand

District	No of site	Capacity(kw)	To be electrified	
			No of villages	
Bageswar	1	500	2	6
Chamoli	2	300	Grid feed	
Pithoragarh	8	375	15	10
Tehri	3	450	8	6
Pauri	1	250	Grid feed	Grid feed
Uttarkashi	2	140	4	1
Rudra Prayag	2	300	2 & Kedarnath Dham	
Total	21	2315		

Table 5 Estimated potential of Small hydro sites in India

(http://www.cea.nic.in/reports/monthly/hydro/2016/hydro potential region-02.pdf)

State	Total		Project installed		Project under implementation	
	No of sites	Capacity ‹mw›	No of sites	Capacity ‹mw›	No of sites	Capacity ‹mw›
Andhra Pradesh	387	978.4	67	219.03	14	34.04
Arunachal Pradesh	677	1341.38	149	103.905	44	22.23
Assam	119	238.69	5	31.11	4	15
Bihar	93	223.05	29	70.7	5	17.7
Chattisgarh	200	1107.15	9	52	4	115.25
Goa	6	6.5	1	0.05	0	0
Gujarat	292	201.97	5	15.6	0	0
Haryana	33	110.05	7	70.1	2	3.35
Himachal Pradesh	531	2397.91	149	587.905	40	122.2
J&K	245	1430.67	35	130.53	9	34.65
Jharkhand	103	208.95	6	4.05	8	34.85
Karnataka	834	4141.12	140	963.758	30	240.992
Kerala	245	704.1	25	158.42	11	52.75
Madhya Pradesh	299	820.44	11	86.16	3	4.9
Maharashtra	274	794.33	51	299.925	16	71.2
Manipur	114	109.13	8	5.45	3	2.75
Meghalaya	97	230.05	4	31.03	3	1.7
Mizoram	72	168.9	18	36.47	1	0.5
Nagaland	99	196.98	10	28.67	4	4.2
Orissa	222	295.47	9	64.3	4	3.6
Punjab	259	441.38	46	154.5	12	21.15
Rajasthan	66	57.17	10	23.85	0	0
Sikkim	88	266.64	17	52.11	1	0.2
Tamil Nadu	197	659.51	21	123.05	0	0
Tripura	13	46.86	3	16.01	0	0
Uttar Pradesh	251	460.75	9	25.1	0	0
Uttarakhand	448	1707.87	99	174.82	46	174.04
West Bengal	203	396.11	23	98.4	17	84.25
A&N Islands	7	7.91	1	5.25	0	0
Total	6474	19749.44	967	3632.253	281	1061.502

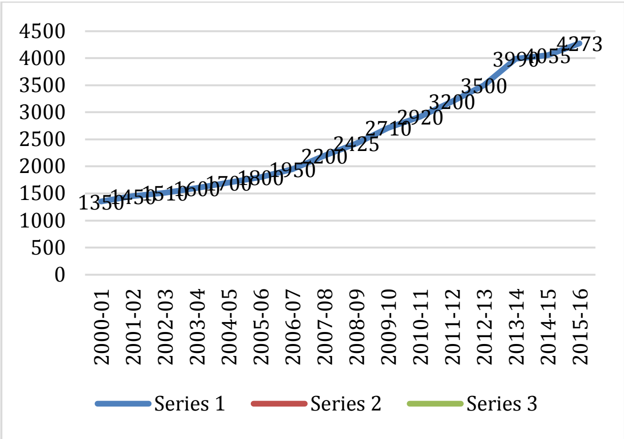

Chart 3 Small hydro power capacity addition

(http://mnre.gov.in/mission & vision2/achievements, www.smallhydroworld.org)

Umanand Kumar, Piyush Singh and A.C.Tiwari reviewed many researchers to analyze available potential, installed capacity and scope of rural electrification of MHP. According to them India is blessed with abundant micro hydro potential but generated power through MHP is 3803.678 MW only which is less than 10% (approx) in total. They recommended to use Screw turbine in MHP because of it's more efficiency and less transmission loss.

G. Ardizzon, G. Cavazzini, G. Pavesi reviewed different research on pump hydro energy system and SHP and signified the influence of these plants in a way to make environment and society more Healthier since these plants are cost effective environment protective and sustainable energy option to electrify remote and hilly areas, where low head water stream are available.

Williams. AA and Simpson. R carried out extensive investigation and simulation of various aspect of PHP to encourage rural development by providing low cost and longer electrical supply. They analyzed integral part of PHP viz. Penstock sizing to achieve optimum economic design and Low head Turbines design and their Characteristic curves experimentally and also verified in CFD.

4. Low head turbines

Turbine is an integral part of SHP, Which convert water energy into mechanical energy. These plants require low head turbines to be installed such that optimum energy conversion can be ensured. Here is list of such turbines (http://www.cbe.eu/data/prospekty/Kaplan turbines. pdf)

Table 6 Low head turbines Ranges

Turbines	Head(m)	Outputs Power	Runner Diameters(m)
Kaplan	May-75	200KW-100MW	Up to 9.5
Bulb/Pit	1.5-30	100KW-20MW	Up to 6
S-type	30-Apr	100KW-10MW	Up to 3.5

Punit Singh and Franz Nestmann carried out holistic investigation regarding the influence of design parameter viz. blade profile, blade height and blade number in MHP. They conducted experiment on 3 runners and found that by increasing number of blades on, runner efficiency decreases steeply due to change indirection of relative flow vector at runner exit, while decreasing runner height there is drastic decrease runner loss coefficient therefore number on runner blades is more dominating than runner blade height.

N.P, Jade S.S Raut, G.A. Wadnere carried out performance analysis by conducting experiment on simple reaction turbine prototypes and found that smaller reactions turbines are more effective and their efficiency increases with increase in rotational speed as well as efficiency also approaches maximum value when load torque is 50% of stationary torque.

A.H. Elbatran, O.B. Yaakob, Yasser M. Ahmed, H.M. Shabara has performed holistic analysis on low head water turbine in a such way that selection of turbine as per requirement of MHP will be not only easier but also provide description, various category, operation , performance and cost analysis of all low head turbines.

5. Concept of PAT

Conventionally to extract water energy turbine are used but these turbines have many constraints to use in small and micro hydro projects. Hence using centrifugal pump in reversed mode (PAT) is sophisticated solution to come over turbines limitation given by researchers for MHP moreover there is detail review of PAT is discussed below

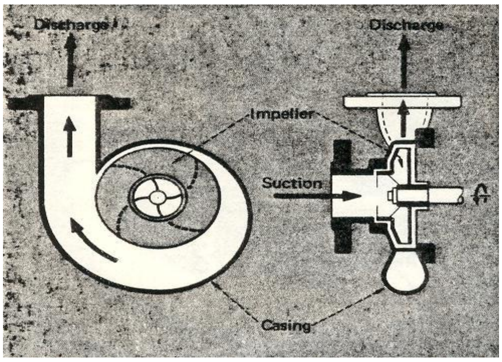

Figure 3 Pump in direct mode (Buse F *et al*, 2012)

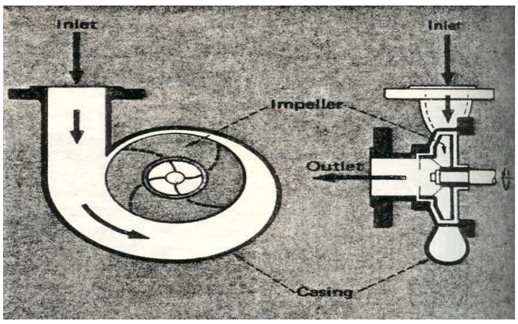

Figure 4 Pump in reverse mode (Buse F *et al*, 2012)

E. Baburaj, R. Shivprakasham, C. Manikandan, K. Shudha have conducted numerical analysis of radial flow pump at specific speed 23.9 in turbine mode by using ANSYS-CFX software. They found that efficiency of pump in turbine mode can be obtained up to 70%. In addition to this they recommended to enhance low cost modification in impeller, fluid structure interaction, casing quality, impeller eye clearance, bearing quality, selection of material for shaft and impeller for further improvement of PAT

Himanshu nautiyal, Varun and Anoop Kumar told that Result obtain by CFD analysis and Experimental analysis of PAT do not match but this difference can be minimized by using finer mesh on CFD software, Numerical analysis and turbulence models moreover CFD analysis is very useful to identify losses in different part of turbines.

Sanjay V. jain, Rajesh N. Patel has reviewed many technique attempted by researchers for performance enhancement of PAT, Impeller blade rounding is found to be most promising and it is recommended to standardize impeller blade rounding effect over wide range of PAT. The efficiency of PAT is usually found to be lower than conventional turbine, however it's operation is recommended at maximum efficiency point.

A Bozorgi, E. Javidpour, A.Riasi, A. Nourbakhsh uses axial flow pump instead of turbine in the PHP was investigated. First they numerically simulated wide range operations on axial flow pump in. Mode and drawn characteristic curves. Next they built experiment setup to test PAT for validating the CFD result and they found that there is good coincidence between CFD and experimental result. According to them Spalart-Allmaras is sophisticated turbulence model efficiency in computational domain of fluid moreover their result shows that axial flow pump is better alternative to turbines used in PHP to generate electricity.

D.R. Giosio, A.D. Henderson, J.M. Walker, P.A. Brandner, J.E. Sargison, P. Gautam have developed 6.5 KW MHP turbine unit to operate pump impeller in turbine mode with spiral casing &guide vane mechanism to control inlet discharge. Experiment indicated maximum overall efficiency 79% and rated power was somewhat higher but discharge was lower than predicted. This system is slightly more complex than traditional PAT.

Sanjay V. Jain, Abhishek Swarnkar, Karan H. Motwani, Rajesh N. Patel Carried out experimental investigation and recommended different technique for performance enhancement of PAT by optimizing geometric and operating parameters viz. impeller dia-250mm, 10% trimmed(225mm), 20% trimmed(200mm) without and with blade rounding and rotational speed 900 – 1500 rpm. Best performance was obtained at 1100 rpm correspond to 10% trimmed impeller i.e. 76.93% efficient. They also developed empirical correlation for best efficiency point and speed and predicted best efficiency was found to be within range of ±10% range of experimental results.

K H Motwani, S V Jain, R N Patel has developed PHP experimental setup of PAT with estimated capacity 3KW. Experimentally they found PAT efficiency 60% which is less than Francis turbine efficiency (80%). However capital cost of Francis turbine is 6 to 8 time greater than available centrifugal pumps. They also analyzed cost of power generated per unit between PAT and turbine were 5.07 and 6.8 respectively moreover easy availability, low maintenance cost and wide ranges of centrifugal pump makes anonymous choice of PAT to run at best efficiency point instead of turbines.

Grunde Olimstad, Torbjorn Nielsen, Bjarne Borresen has measured characteristics of five different profile of reversible pump in turbine mode. These profiles were varied geometrically and their numerical as well as CFD simulation was performed. They found that pump in turbine mode has much steeper flow-speed characteristic slope than Francis turbine, numerical and CFD simulation of profiles shows that smaller blade angle and long-radius leading edges result in less steep characteristics. According to them characteristics can be altered by very small changes on inlet blade angle without influencing characteristics near best efficiency points. They recommended-to increase the radius of curvature on pressure side of leading edge, decrease the inlet radius, increase inlet blade angle or increase length of blades to make PAT more stable.

Himanshu Nautiyal, Varun, Anoop Kumar, Sanjay Yadav has experimentally tested characteristics of centrifugal pump (CFP) as PAT and PAP at specific speed 18. They found that CFP can be use as turbine without any technical or mechanical issue moreover CFP operates at higher head and discharge in PAT than PAP. The best efficiency of CFP as PAT is 8.53% less than PAP. They also develop relations to predict PAT characteristic by using PAP relation made by different researchers and concluded that developed relation gave more accurate result of PAT from PAP data.

Tarang Agarwal reviewed many researchers and concluded that PAT is incredible alternative to install MHP in remote areas because of low capital cost moreover cost can be further reduced by specific selection of PAT for different location.

P. Vasanthakumar, A. Arulmurugu, R. Vinoth kumar, R. Gowtham kumar , S. Kumaresan, V. Prasath reviewed complete detail for selection of CFP as Turbine for MHP. They recommended future work for performance enhancement of PAT are low cost modification in impeller diameter, impeller flow inlet–outlet zone, fluid structure interaction and material selection for impeller and shaft.

Yang Sun-Sheng, Kong Fan-Yu, Jiang Wan-Ming, Qu Xiao-Yun carried out numerical and experimental investigation to analyze effect of impeller trimming on single stage centrifugal PAT. Experimentally they found that flow rate at BEP changes from 95.23 m^3/h to

86.14m^3/h and then move back to 93.63 m^3/h, hence efficiency dropped by 4.11%, Q-H curve of PAT becomes steep and Q-P_{shaft} curve is almost parallel as impeller diameter decreased from 255 mm to 215 mm. In CFD simulation they observed that as impeller diameter decreases from 255 mm to 215 mm, the flow rate and efficiency at BEP decreases by 20 m^3/h and 2.08%. Deviation between CFD and experimental results are due to neglection of volumetric leakages losses.

R. Barrio, J. Fernández, J. Parrondo and E. Blanco carried out experimental and CFD investigation of pump in direct and reverse mode and observed good agreement between both investigation flow characteristic. They observed that while operating as turbine, flow match with geometry only at nominal condition and make re-circulatory region of fluid at high and low flow rates. This region of fluid may be either pressure or suction side of the blade and low pressure region is present between impeller and tongue.

Yang Sun-Sheng, Kong-Fan-Yu, Fu Jian-Hui and Xue Ling carried out numerical investigation into splitter blade to performance influence of PAT. They observed that PAT efficiency increases, required pressure head and pressure fluctuation decreases when splitter blade are added to the impeller flow passage additionally maximum pressure point is located before the tongue in the Volute.

Conclusion

India Being one of the fastest growing countries where per capita energy consumption increasing sharply due to rapid economic expansion, However India still depends largely upon fossils fuels , which are environmentally hazardous and have limited exploitable amount but these fuels are contributing more than 70% electricity generation in the country. Now there is vital need to look for environment friendly sustainable energy resources to make the climate more prosperous. From above study, it can be concluded that Hydro power can be a benchmark to boost current energy demand moreover for rural and remote area's electrification, Installing PAT instead of turbine on MHP/SHP is fabulous solution as installing and operating cost is low in comparison to conventional turbines. In addition to this wide variety, availability and low maintenance cost of centrifugal pump makes PAT an anonymous choice. Performance prediction of PAT is slightly difficult because experimental and simulated data deviate, but there are number of recommendation of researchers cited above to reduce this deviation tremendously. Scope of Future work lies in improvement in the performance of PAT at BEP by implementing recommendation made by researchers and further investigation through CFD will provide comprehensive understanding of PAT.

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