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A review on turbines for micro hydro power plant

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ABSTRACT

In recent years design of micro hydro power plants has been examined by various groups throughout the world due to its merits of offering better performance than the conventional fossil fuels to meet the energy need. Considering the portfolio of energy, the improvement of hydro power will partake in decrease of greenhouse gas emission and better malleability in the grid operation. This inquisition study examined the turbine of small hydro plant from the perspective of efficiency improvement while maintaining the global cost of the project per kW arrive within confined range. In this documentation an extensive epitomize of turbines available in India and other countries has been described. The selection of head, runner diameter along with its accomplishment are also presented. This study reveals an improvement for the design of turbines while comparing the functioning of other existing system for similar operating condition. Since most power plants now-a-day's use large turbines for the low power production, losses and overall cost increases, hence this survey will be helpful to reduce the cost of the plant. The reviews mainly focus on the study of existing turbines upto 100 kW. The importance of the turbine in micro hydro projects with respect to our current energy scenario is also highlighted.

1. Introduction

The power shortage is a major hurdle India had to face. For the country's economy to sustain, electricity is the artifact of it. A stand alone electric power generation [1] using renewable resources is one among the most required and productive methodology to generate electricity. Especially in places lagging grid connection, such as rural side of the country micro hydro power is an important resource [2–4] in which electricity is generated by converting the potential energy of water which stands as the puriest form of energy in the world. The water thus generated is also kept for irrigation [5–8] and other domestic purposes after generation of electricity. The concept of using running waters to generate electricity was begun by the introduction of water wheel in Wisconsin in 1882 at the Fox river. In this century hydro power had marked a place in electrical energy production around the world. The power generation various from plant to plant depending on several aspects and those plants which generate electricity lesser than 100 kW are termed as micro hydro power plants. These small hydro plants consume less space, reliable and cost effective then the fossil fuels [9]. Due to its salient features it pays a path in establishment and development of small sized hydro plants in the country rather than the mega hydro projects that occupies more space [10].

Huge number of sites with high potential and greater demand for electricity have been identified as low head pico resources and use of such potential sites is important [11,12]. Several of the pico hydro plants are located in forest range or in remote areas [13]. The main issue faced by these plants is the inadequate supply of turbine or high cost [14]. The heart of any micro hydro project is the turbine that is capable of generating electricity through the rotation of the shaft. Hence much attention had to be taken in genuine choice and performance of such turbine [15] as the clue rest in the coherence transfiguration of the energy in the water to useful electrical energy. According to head, turbines are classified [16] as

a) Low Head (upto 40 m) – Propeller and Kaplan Turbine.
b) Medium Head (40–100 m) – Francis, Pump as Turbine, Cross Flow and Pelton Wheel.
c) High Head (> 100 m) – Turgo and Pelton Wheel.

Even though lot of research work on hydro power plant design had been reported in the previous years, most of them are confined to either medium or large hydro power plants. Since the present study is focused on micro hydro power plant and no study has been reported for turbine that are used for micro hydro power plants, if a suitably low rated turbine were to be readily available in the market, then the operational cost of micro power generation would be considerably lower. The

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reason for non-availability of these turbines in the local market is mainly because of their limited demand from only South India on account of the existence of many waterfalls of lower heads here. If the production of these low rated turbines is enhanced then the whole of South India would generate greater amount of electricity thereby resolving the power shortage to a large extent. The non-availability of suitably rated turbines in the market is an eye opener for the researchers in the field of turbine development, as indicated in the above survey of this paper. Hence this present research work is focused on turbines pertaining to the review small and micro hydro plants.

2. Micro hydro power plant – a study

Hydro power is the harnessing of energy from the flowing waters that are converted into useful mechanical form [17], thereby generating electricity by using a generator. Few of the hydro power systems are classified as micro hydro power system when the energy generating capacity of the plant is within 100 kW [18,19] then it is termed as micro hydro power system. They are relatively small power sources that may be used to supply power to a small group of communities, who are independent of the general electrical supply grid [20].

In a typical micro hydro power plant as shown in Fig. 1, the river waters passes through the forebay tank and reaches the turbine. The turbine converts the hydraulic power into mechanical energy. The mechanical energy is subsequently then converted into electrical energy by a generator. The presence of a forebay tank aids in continues supply of water to the system [8]. The hydraulic system also comprises of a valve control system and the system will be able to produce maximum power only if the gate valve is kept fully opened. The mechanical power thus generated is send to the electrical unit which comprises of the synchronous generator connected to a shaft to produce useful electrical power to pamper the wants of the rural community and thus the water is released back to the river or stream without causing erosion [6].

3. Review on turbine manufacturers in India

Table 1 gives the details about the review on turbines manufacturers in India. The need of energy had paved path to the development of several turbine manufactures in India but the interested parameter is that lower power rated turbine design are in scarcity.

Silver Boat Technologies Pvt. Ltd [21] are known for the scheming and conniving of pico [22,23] and small hydel systems of a wide scaling of 1–100 kW. All the system fabrication is done by Silver Boat Technologies Pvt. Ltd in India and their turbines can be used for both grid and off grid conditions with higher efficiency and reliability.

Ytek [24] is an organization connecting themselves in the component development for micro hydro projects such as extending their help in designing of control equipments for system and also focuses on industrial automation. They cater on micro hydro projects situated in tribal regions of the country which are rich in potential and are off grid and thus can be automated.

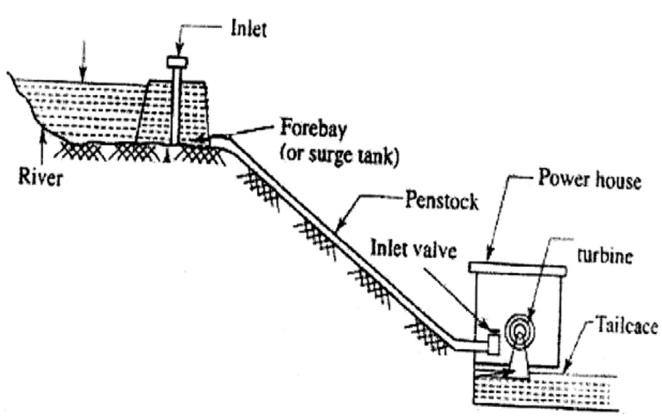

Fig. 1. Schematic of a micro hydro power plant [2].

Table 1
Turbine manufacturers in India.

S.No	Turbine Manufacturer	Output Power (kW)
1	Silver Boat Technologies, Chennai [21]	1–100
2	Ytek Controls, Dehradun [24]	5–100
3	Ape Power Pvt. Ltd, West Bengal [25]	5–100
4	Wasserkraft, New Delhi [26]	5–200
6	Vaigunth Enertek Pvt. Ltd, Chennai [27]	10–200
7	Flowmore Ltd, Haryana [28]	upto 20000
8	Karshni Intertech Pvt. Ltd, Noida [29]	5–100
9	Pentaflo Hydro Pvt. Ltd, New Delhi [30]	5–100
10	Centre for Energy Initiatives, Bangalore [31]	5–100

APE Power Pvt. Ltd [25] also dealers in turbine development of micro hydro projects and have expanded their work on commissioning and execution of the micro hydro plants. Their turbine production starts from 5 kW turbines and ranges upto 100 kW turbines.

In the state of Kerala, six high potential waterfalls were indentified in the year 2001 by framing their project strategy in electrifying the rural community residing near Mankulam Panchayat in Idukki District. The commissioning of the plant was started in 2001 and it takes the pride of establishing the first off grid hydro project of 110 kW at Pampumkayam, Kerala with a catchment area of 8 Km^2. The project thus progressed and reached the stage of developing the penstock line after which in 2002 the project showed less progress due to the financial need of purchasing the turbine. At this juncture the United Nations Industrial development Organization Regional Centre (UNIDORC) played a vital role in restarting the work of purchasing two generators from china with 55 kW each. All the purchase of the components were done through UNIDO's International Centre on Small Hydro Power (ICSHP). The other economical details of the projects states that the project cost upto Rs. 6.7 million. Another project done in Idukki District was by the Energy Management Centre (EMC) which equipped 2×50 kW horizontal shaft Francis turbine with 100 kW as the output power of the plant and was also approved by the Kerala State Electricity Board (KSEB) [32].

3.1. Inferences from the review on turbines manufactures in India

Various dissertations have been outlined in the documentation of small hydro power plants. Table 1 evidently states that the cost of the plant will naturally increase because of the use of higher rated turbine for low power generation. Despite of the enormous development in the design of small hydro power plant, the plant has certain drawbacks. It is to be closely observed from Table 1 that all the turbine manufactures produces turbine of capacity in the range between 5 and 100 kW and one manufacture from Haryana generates a high powered turbine of 20000 kW [28] and these turbines are used for micro hydro projects as well. Thus, proving evidently that there are no special turbines for micro hydro projects.

Due to these parameters, first, the cost of the plant will be more. Second, erection of the turbine for micro hydropower plant is tedious. A majority of the results that are available are of either for a pico plant or a 100 kW plant and even if it is 50 kW turbine it is been exported. The cause for confined reviews of turbines would be that such turbines of specific rating might not be mobilised in market but the requirement of such turbines is more to electrify the rural community who needs an nominal power generation and not an higher powered turbines. The fact remains conspicuous that more research is to be carried out in future to electrify the rural community with cost effective adaptive turbines.

Table 2
Turbine manufacturers outside India.

S.No	Turbine Name	Output (kW)	Head (m)	Flow rate (l/s)
1	ENC-025-F4 [33]	25		
2	ENC-025-R5 [33]	25		
3	ENC-025-F4 [33]	25		
4	CJ-10 High head [34]	10	30–38	40–50
5	CJ-6 High head [34]	6	28–35	30–38
6	CJD-10High head [34]	10	25–30	50–60
7	CJD-12 High Head [34]	12	28–35	50–60
8	CJD-15kw High head [34]	15	30–40	60–70
9	CJD-20 [34]	20	30–45	60–100
10	CJD-30 [34]	30	38–45	90–120
11	MH-10 Medium head [34]	10	11	165
12	Pelton turbine Pt 350/110 [35]	100	114	
13	Cross flow turbine [35]	80	214	
14	Dual wheel dual jetpelton impact type small water turbine generator [36]	18	22–60	0.129–0.047
		26	25–70	0.156–0.056
		30	28–70	0.156–0.063
		40	30–80	0.189–0.071
		55	35–80	0.214–0.093
		75	40–100	0.248–0.1
		100	40–100	0.331–0.132
15	Volute Axial Flow low head micro turbine generator [36]	1	2.5–6	0.085–0.035
		1.5	2.7–8	0.114–0.0382
		2	3–10	0.128–0.0385
		3	3–12	0.185–0.0464
		5	3.5–15	0.251–0.0586
		8	4–16	0.352–0.088
		10	5–18	0.34–0.094
		12	5–18	0.395–0.10
		15	5–18	0.47–0.132
16	Volute axial flow small hydro Water turbine generator [36]	30	6–18	0.728–0.243
		40	7–18	0.81–0.315
		55	7–20	1.07–0.374
		75	8–20	1.24–0.497
		100	8–20	1.66–0.662
17	Incline jet pelton permanent magnet water turbine generator [36]	1	10–20	0.012
		1.5	15–20	0.015
		2	15–25	0.02
		3	15–30	0.025
		5	20–50	0.035
		8	25–60	0.045
18	Pelton double nozzle hydro turbine generator [36]	30	10–60	
19	Maraig micro hydro [37]	49.6	29.5	249
20	Gilbert Gilkes and Gordon Limited [38]	0.05–100	5–300	0.5–1000

4. Review on turbine manufacturers outside India

Several literature reviews has been done by the authors to find out the availability of turbine manufactures outside the country. Table 2 lists out manufacturers of turbine, outside India. Turbines listed from 1 to 8 are manufactured in South Africa, while that from 9 to 11 are manufactured from New Energy Corporation Inc, Canada.

Table 2 presents the availability possibility of turbines that can be developed either in series or in parallel within rivers but for manmade canals series arrangement of turbines had to be incorporated [33].

Table 2 furnishes details about the turbine manufactures around the world [34–38] and these turbines are designed site specific with definite head, flow rate and efficiency of the hydro power plant [33].

Xinda Green Energy pioneers of wind turbine generator, also work on turbines for small power generation ranging upto 100 kW but their major focus is on hybrid system, electric motors, street lamp and so on in global market [36]. Highlandeco recently completed the installation of a 9 kW hydro turbine at Grimshader just south of Stornoway after helping the croft owner, Kenny MacArthur, to build the scheme himself [37].

Canyon hydro designers manufacture turbines for a very wide range of 4–25 MW. Every system is fabricated and developed at their facilities in USA. Their fabrication facilities are so precise and capable of producing efficient, cost effective and reliable turbines for the small hydro projects [39]. Canyon hydro designers also provide a wide option in selection of turbines [40] which is below 100 kW so as to facilitate the customers for small power developments.

4.1. Inferences from the review on turbine manufactures outside India

The observations based on the reviewed literature of turbine manufactures abroad, makes us to conclude that even though turbine of lower rated power are manufactured in abroad and delivered to their country people in an reasonable rate, all the spare parts are designed at their country itself and not outsourced and importing of the same to India will lead to larger cost in the erection of the power plant. Secondly the manufactures concentrate on the entire renewable development and not in specific to the design of the hydro turbines only [22]. From Table 2, the largest head measured upto 114 m and 214 m in S.No 12 and 13 which uses Pelton and Cross flow turbine respectively [35]. Irrespective of the flow rate of the resource the plant yields an output power of 90 kW on an average. Another manufacturer considered a head of 300 m [38] as mentioned in S.No 20 of Table 2 has the capability of producing 0.05–100 kW power with a flow rate of 0.5–1000 I/s.

5. Review on turbines in published literature

Bozorgi [14] analyzed an axial pump as turbine for pico hydro power plants both numerically and experimentally. The results of the analysis showed that a good correlation is there between the numerical and experimental results.

Date [41] in his paper focuses on three fold work. The first fold deals with the performance analysis with split reaction water turbines. Secondly he worked on the design details and arrived at the conclusion that the efficiency of the turbine will be better if the turbine spins faster and to achieve faster spinning of the turbine the machine diameter had to be maintained smaller. Finally he had worked on the power production and surveying of a real site in Australia along with the layout of the plant.

Motwania [42] used the concept of computational fluid dynamics to simulate the axial pump. He operated the pump in reverse flow so as to use it as a turbine. The head, power and the flow rate was measured and to do this a test setup was developed and operated in the reverse mode. The author concluded that the pump operation was done successfully and it performed as a turbine yielding higher efficiency.

Alexander [43] worked on lower head micro hydro plants and designed four different propeller turbine of specific speed. The head of the hydro plants taken into consideration was 2–40 m. The author presented all the test results and the dimensions of all the four turbines and arrived at an hydraulic efficiency of 68% in all the turbine models. Thus the paper was presented for wider range of head turbines.

Derakhshan [44] investigated on various centrifugal pumps with a synchronous speed lesser than 60 rpm. With the help of real time experimental values the pump design was done and allowed it to operate as a turbine. Several equations were used and the validation of how the pump is operated as a turbine is also been presented in the paper.

Sinagra [45] in his paper presents the manufacturing and construction of a cross flow turbine which is sought after, assuming a flow rate variable in time. Regulation of the discharge entering in the turbine is a key issue. For his analysis he had adopted that the velocity at impeller inlet is at least twice lesser than that of the velocity of the particles reaching the impeller. These settings enabled him to attain the maximum efficiency of the turbine. Thus in his paper he had worked on maximizing the efficiency of the turbine and proposed a new design using Computational Fluid Dynamics (CFD) simulator and finally validated the results by applying in a real site in Sicily. Thou the author has presented a design methodology for the turbines, it was not adopted in India and thus there is a void in research in this field.

Ikeda [46] presented about the design of nano turbines for waterfalls with variable head and employed various studies and came to a conclusion that the power performance of rotor is influenced on how far the rotor is placed from the waterfalls. Here he employed multi centrifugal pump in parallel arrangements which are made to work as turbine. Furthermore the study results based on installation parameters is also presented.

Yassi and Hashemloo [47] analyzed the improvement in efficiency of an axial turbine at part load condition. The improvement in design is the incorporation of guiding vane mechanism that improved the efficiency of the turbine by about 23%.

Yadav [48] with his noble and native concept tried to increase the efficiency of the turbine with the modification in the blade and with some auxiliary attachments which will lead to less wastage of the head and result in better efficiency.

Chandran et al. [49] evaluated the performance of a cross flow turbine experimentally. The maximum efficiency of the turbine was found to be 55% for a head of 8–10.5 m at 100% guide vane opening and at a speed of 1500 rpm.

Andrade et al. [50] investigated numerically the internal flow in a Banki turbine. A 3D-CFD steady state flow simulation was performed using ANSYS CFX codes. The results of the numerical analysis was compared with that of experimental data and a good consistent between them was observed. A 75% maximum efficiency was obtained at a runner speed of 900 rpm.

Pereira and Borges [51] experimentally estimated measured the efficiency of a cross flow turbine. Tests were performed for a maximum head and maximum discharge of 5.5 m and 100 l/s, respectively and a peak efficiency of 85% was attained.

Khan and Badshah [52] analyzed a cross flow turbine using Ansys 13, for a head of 6 m and discharge 175 l/s. Sewerage water was used to run the turbine. An efficiency of about 60% was obtained for an optimum of 36 number of blades.

Girma and Dribssa [53] carried out CFD simulation using GAMBIT and Ansys Fluent. From the study it was observed that a maximum efficiency of 83% was achieved at a head of 3 m and discharge of 420 l/s.

Acharya et al. [54] performed numerical analysis to improve the performance of a cross flow hydro turbine. The results showed that the efficiency obtained was 63.7%, which was geometrically modified that improved the efficiency by 13%.

Williams [55] utilized a centrifugal pump integrated with an induction motor as a combination of turbine and generator for micro hydro power plants. The unit was found to be cost effective and a suitable alternative to cross flow turbines for power output upto 5 kW in industrialized and developing countries.

Bryan and Kendra [56] carried out investigations on the performance characteristics of both Pelton and Turgo impulse turbines intended for pico hydro power applications. The efficiency of both the turbines was observed to be around 80% at a speed ratio of 0.46. The study also revealed the important of a proper system design and installation for better implementation in pico hydro power plants.

Date et al. [57] investigated two simple water reaction turbines of rotor diameters 0.24 m and 0.12 m for low-head micro hydro applications. The turbines were tested under a head of 1–4 m and its conversion efficiency was found to be about 50%.

Williamson et al. [58] performed theoretical and experimental analyses of a low head pico Turgo turbine. The efficiency of the turbine at 3.5 m and 1 m head were found to be 91% and 87% respectively. The results of the experimental analysis were found to be in good agreement with the theoretical one.

Huang et al. [59] analyzed experimentally a novel three bladed vertical axis 3 kW micro hydro turbine. The turbine system used a three-phase permanent magnet symmetric generator that convert mechanical energy into electrical energy. The experimental results showed that the speed ranges of the water flow are narrower than those of wind, and the status transformation from cut-into stable power generation was short. The study also showed that the efficiency of the turbine was constrained by stream flow speed and crossover section area.

The performance, operation and economic analysis of low head turbines for micro hydel power applications were reviewed by Elbatran et al. [60]. They analyzed the effectiveness features of various types of turbines as well as the significant factors that affect their operation and performance. The authors also provided a guideline for selecting the most suitable turbine for use in different low head and micro-hydro power plants.

Židonis et al. [61] highlighted the recent developments in the design of Pelton and Turgo impulse turbines and opportunities for future development. The study proved that a significant increase had been made in the computational fluid dynamics for the development of Pelton and Turgo turbines. The study also proved that the simulation results of a Pelton turbine simulations were found to match with the experimental results and detailed analysis are required for achieving the same in a Turgo turbine.

Giosio et al. [62] developed a low cost micro hydro turbine of 6.2 kW power output utilizing a pump impeller as runner and incorporated inlet flow control. The developed unit covered a wide operating range and attained a maximum efficiency of 79%. The designed micro-hydro turbine unit addressed the main drawbacks of pumps operating in turbine mode, providing a low cost alternative generating solution for application in remote area power supply and found to a great potential for power supply in remote areas and energy recovery system.

An experimental investigation of design parameters for pico hydro Turgo turbine using response surface methodology was done by Gaiser et al. [63]. The design parameters such as nozzle diameter, jet inlet angle, number of blades, and blade speed were used in a three-level (3^4) central composite response surface experiment. A low-cost Turgo turbine was tested and a second order regression model was developed to predict its efficiency. The effects of blade orientation angle and jet impact location on efficiency were also investigated.

Khan et al. [64] analyzed a micro hydro turbine to recover flow conditions for optimum power generation. Turbine geometry modeling was done using computational fluid dynamics (CFD). CFD analysis of the turbine geometry with different configurations of debris protectors was carried out to evaluate the optimal recovery of flow properties for maximum electricity generation.

5.1. Inferences from the review of turbines in published literature

Several researches had been carried out and the efficiency of the system is also been presented by different authors in the above mentioned papers. The general observations in all the above presented research article is that there is a void in designing of turbine in Indian markets. Table 3 gives a consolidated picture of the review on turbines in published literature. It is inferred that in the last 5 years the need for designing a reliable and cost effective turbines for the installation of a

Table 3
Summary of the investigations of turbines in published literature.

S.No	Author	Turbine	Net Head (m)	Discharge (l/s)	Output (kW)	Efficiency (%)
1	Bozorgi et al. [14]	Axial Pump as Turbine	4	200	6	61
2	Date et al. [41]	Reaction Turbine	1.45	30	0.28	65–70
3	Motwania et al. [42]	Single Stage Centrifugal Pump Turbine	15	25	3	60
4	Alexander et al. [43]	Propeller Turbine	4–9	–	20	68
5	Derakhshan and Nourbakhsh [44]	Pump as Turbine	25	150	30	
6	Sinagra et al. [45]	Cross Flow Turbine		820		89
7	Ikeda [46]	Nano Hydraulic Turbine	1.2	1–3	0.1–0.2	20
8	Yassi and Hashemloo [42]	Axial (Kaplan) Turbine	24	117		85
9	Chandran et al. [49]	Cross Flow Turbine	8.5–10	10–70		55
10	Andrade et al. [50]	Cross Flow Turbine	35	135		70
11	Pereira and Borges [51]	Cross Flow Turbine	5.5	100	3.5	85
12	Khan and Badshah [52]	Cross Flow Turbine	6	175	6.2	60
13	Girma and Dribssa [53]	Cross Flow Turbine	3	420	2.5	83
14	Acharya et al. [54]	Cross Flow Turbine	10	100	7.3	77
15	Bryan and Kendra [57]	Pelton and Turgo Turbine	13–28	–	< 5	80
16	Date et al. [58]	Simple Recation Turbine	1–4	1–8	0.150	50
17	Williamson et al. [59]	Turgo Turbine	1–3.5	10	0.250	87–91
18	Giosio et al. [63]	Pump as Turbine	5.98	133	6.2	79

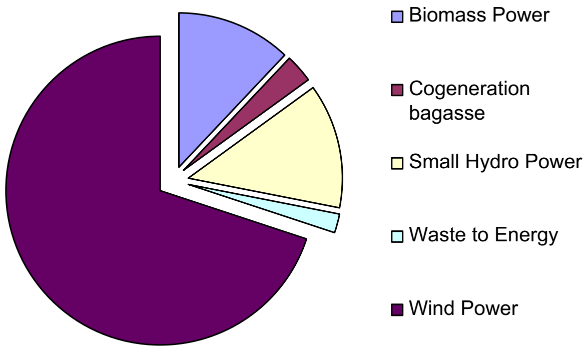

Fig. 2. Source wise estimated potential of renewable power in India (as on 31.03.2014) [65].

micro hydro power plant is very essential due to the scarcity of energy. Especially for a country like India which is rich in potential in renewable power (Fig. 2) and especially in small hydro power as shown in Fig. 3 increases the need for development of turbines. Furthermore these sorts of advanced turbines if developed designed and commissioned in India will be useful for the upliftment of the rural and tribal citizens of the Indian Democracy. Thus paying path to the research need in the fabrication and development of turbines for micro hydro systems.

6. Conclusion

The present review is a comprehensive one on the research progress made in the turbines in the published literature, used for micro hydel power applications. The present work also highlights the availability of turbines with the manufacturers both in India and abroad. The salient feature that can be drawn from this work is that efforts have been made by researchers to enhance the efficiency of the turbine used for micro hydro resources. However, there is a research gap from the viewpoint of design of turbines that large powered turbines are currently being used for low power generation (Tables 1–3) in hydro power plants. This research gap presents a great challenge to the researchers as turbines which are designed to cater to these specific needs only would be cost effective and reliable for the implementation in hydro power plants. Based on the promising results presented in the literature, it seems that the research activities on the design of turbines for specific needs would increase in future.

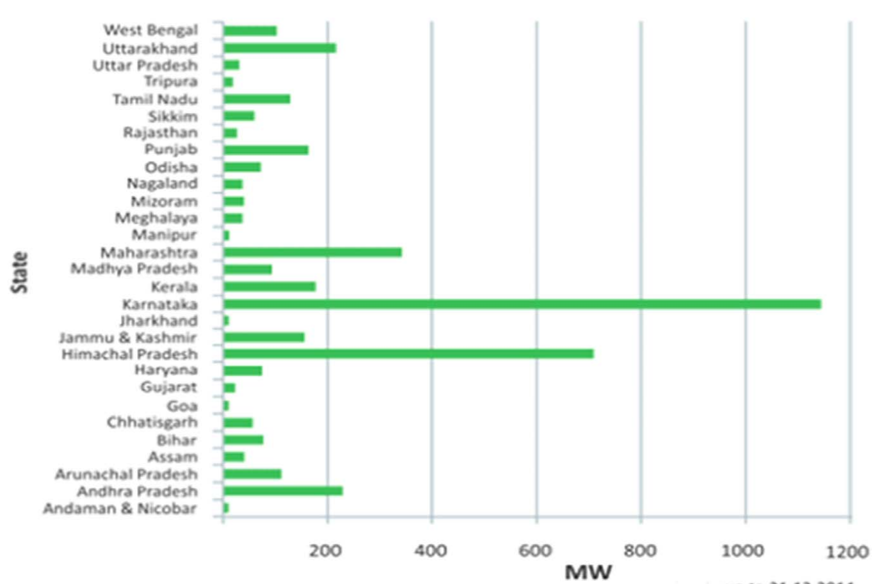

Fig. 3. State wise installed capacity of small hydro power [66].

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