Master Thesis

Design and Manufacturing of 3D Printed Propeller Turbine for Pico Hydro Applications

3D 프린터를 이용한 미소수력 프로펠러 터빈 설계 및 생산

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Abstract

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There are a lot of low head sites in isolated areas, especially in third world countries, where pico and micro hydro-power are realistic energy option as national grid extension to those places are unlikely because of sparse population and high transmission cost. While implementing pico/micro hydro system in developing countries turbine manufacturing cost is one of the bottle neck. Since a large chunk of the cost is used in manufacturing of turbine, we've proposed to use the 3D printed turbine (made from ABS- a kind of thermoplastic) in order to reduce the significant amount of cost. Furthermore using 3D printer proper turbine shape can be achieved even at miniature turbine which helps to match the theoretical efficiency. The cost of 3D printing is decreasing drastically so a power generating unit can be delivered to developing countries within few dollars. The goal of the research is to provide low cost, propeller turbine that provides around 300W of electricity with 2.5m and 30 lps flow rate. The electricity thus generated will be sufficient enough for a household and lighting purpose in third world countries.

Keywords: Pico hydro, propeller turbine, axial flow turbine, 3D printing

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CHAPTER -1

INTRODUCTION

1.1 Background and motivation

The non-renewable nature of fossil fuel and increasing energy demand has made it scarcer than before and therefore its price is skyrocketing. On the other hand renewable energy like wind, solar are omnipresent free and abundant in nature (and certainly won't be scarce in future). Since the renewable technologies are improving the electricity cost produced by renewable form are certainly going to decrease significantly in near future [1]–[3]. Energy crisis, ever increasing oil prices, climate changes due to greenhouse gases and limitations imposed by Kyoto protocol in production of these gases has increased people's attention towards effective, efficient and sustainable and almost pollution free renewable energy systems.

Hydropower is a renewable energy source that converts the energy from water flowing from higher to lower elevations. Hydropower are the largest source of renewable energy in electricity sector and contributed 16% of worldwide electricity supply in 2008 [4]. Hydropower is a proven, mature and predictable technology. They have the best conversion efficiencies among all known energy sources (water to wire efficiency of 90%) [4].

The grid electricity extension in case of isolated areas and also in third world countries is unlikely because of the high extension cost and sparse population. Renewable energy sources are considered to be most economically viable options in those areas. The water flow is mostly predictable as it changes with the season and month of year which makes hydro system less stochastic then then solar and wind [5] . An off grid pico/micro hydro system is the most reliable and often the only way to meet energy demands in areas of developing countries. Small hydro power plants are not only good technological solution for electrification in disperse communities in developing countries but also can be a good solution in industrialized and developed countries. Figure 1 shows the comparative study off grid electricity generation cost performed by World Bank Group Energy Unit [6] which shows that the pico hydro power generation cost is below $ 0.2 /kW which is the lowest energy generation cost among other off grid energy options. As larger hydro power sites are already exploited in developed countries, small hydropower sites are abundant and also their relatively small environmental impacts make then cynosure among energy community. Small scale or micro/pico hydropower does not only exploits river's hydropower but also slows down climate change along with creating employment opportunity with additional benefit of low cost. Pico/micro scale hydro power can also be used for other purposes like irrigation, domestic water supply and other house hold purpose [7].

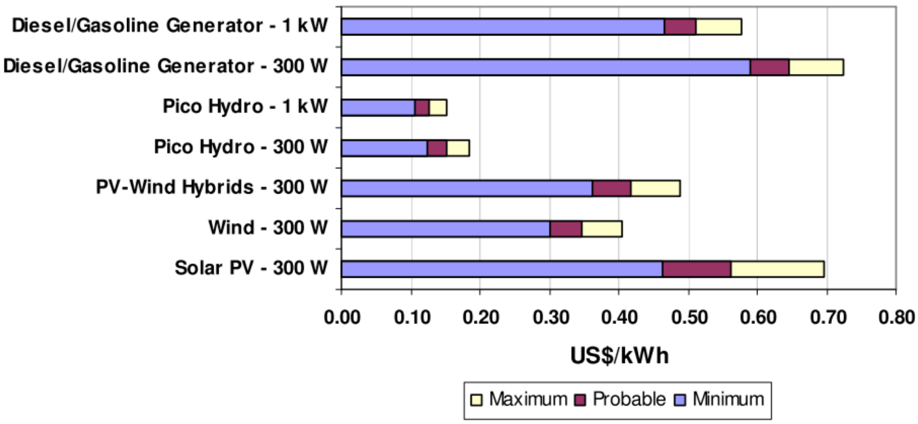

Figure 1: Off grid electricity generation cost [6], [8]

1.2 Objective

The objective of this research is to design a propeller turbine and study the possibility of using 3D printed turbine made of ABS thermoplastic. As the strength of the ABS is comparatively lower than the cast iron, some strategies for increasing the strength of the 3D printed turbine has also been developed.

CHAPTER- 2

HYDRO TURBINES FOR PICO HYDRO APPLICATIONS

Micro and pico hydro power are generally "run-of-river" type with a very small dam or barrier and almost no or very less water is stored. The civil works in the micro and pico hydro has only function of maintaining the water level so they don't have adverse effect on local environment like larger hydro power systems [9]. Though in the global energy supply the primary role of hydropower is to provide central energy network, small pico and micro scale plants are operated in isolation to meet or complement the electricity demand of a single person or family.

There is no internationally agreed consensus on the classification of hydropower systems based on their installed capacity due to difference in policies adopted by countries [4], [9]. In the jargon of hydro power industry, 'pico-hydro' refers to capacity below 10kW, 'micro-hydro' refers to hydropower below 500 kW, mini hydropower refers to schemes below 2 MW.

Table 1: Hydropower classification based on power [8]

Classification	Power output
Large	> 100 MW
Medium	10 -100 MW
Small	1 - 10 MW
Mini	100 kW – 1 MW
Micro	5-100 kW
Pico	< 5 kW

2.1 Hydro turbine classification

The turbine is a rotary machine that converts moving stream of water into mechanical energy. The basic element of a turbine wheel is its blade. When water hits the blade the turbine rotates and the mechanical energy is transferred to the shaft to operate machine, compressor or and electric generator. Pelton, Francis and Kaplan are the most widely used hydro turbine in large scale hydro electricity generating plants. Turbines that are most widely used turbines in pico and micro hydro applications are explained later in this section.

2.1.1 Impulse turbine

In an impulse turbine the total energy head of the incoming fluid is converted in to a large velocity at the exit of the supply nozzle. The pressure of the liquid occur only in the nozzle of the machine there is no pressure change while liquid flowing through the rotor of impulse turbine. Pelton and Turgo are the common type of impulse turbine. These kind of turbines are best suited for high head and low flow rate situations. Pelton turbines for pico hydro applications are discussed in literature [10]–[12]

2.1.1.1 Pelton turbine

Pelton turbines consists of split buckets set around a rim and hit tangentially by high velocity water. The high speed water when hits the bucket is split into half and is turned and deflected almost by 180^0. The turbine rotates as a impulse from the jet while water falls down into the discharge channel. Pelton turbine is generally used for high head sites.

2.1.1.2 Turgo turbine

A Turgo turbine is similar to Pelton turbine but the water hits the bucket at an approximately 20 degrees angle and the water enters from one side of the turbine and exits from the other sides. There is no interference from the returning water jet as in Pelton turbine so for same specification the diameter of the Turgo turbine is smaller than that of the corresponding Pelton turbine [9].

2.1.1.3 Crossflow turbine

A crossflow turbine is cylindrical water wheel or runner with horizontal shaft composed of blades (up to 37) arranged radially. Water jet enters the top of the rotor through the curved blade and exits from further side of the rotor by passing through blade two times which gives additional efficiency. Most of the other water turbine have axial or radial flows but in cross flow turbine the water passes through the turbine transversely. Cross flow turbines for pico hydro applications can be found in literature [8], [13], [14]

2.1.2 Reaction turbine

In a reaction turbine pressure of the liquid changes while it flows through the rotor of the machine. The reduction in pressure and change in the fluid velocity causes a reaction on the turbine blades; that is from where the turbine got its name. In a reaction machine, the rotation of the runner is partly because of the reaction and partly due to change in the pressure over runner blades. These kinds of turbine are well suited for medium to low head and high flow rate devices. Propeller (with Kaplan variant) and Francis turbine are the typical type of reaction turbines.

2.1.2.1 Propeller turbine

Propeller turbine applies the conventional theory of propeller acting in reverse direction to harness the kinetic energy of the fluid. A propeller turbine consists of at least of two blades on opposite side of the shaft. Various configuration of propeller turbine are available and almost all of them require for a swirl before entering the turbine which is often given by guide vanes. The guide vanes of the turbine can be adjusted to match with the flow. The propeller turbine with adjustable blade angle is called as Kaplan turbine. Turbine blade angle and guide vane angle varying mechanism is generally complex and expensive so it is generally used only in large systems. Low head fixed geometry propeller turbines is the most cost effective turbine design option [15].

2.1.2.2 Francis turbine

Francis turbine is a modified form of propeller turbine [9] in which the water flows into the turbine radially and emerges axially. They are equipped with spiral casing with adjustable guide vane. Francis turbines are the most widely used turbines in large scale hydropower.

Comparing the efficiency of the various type of turbine Pelton, Cross flow and Kaplan maintains their efficiency even while running at below rated flow while there is drastic fall in efficiency in case of Francis turbine if operated below 50% of rated flow. While in case of fixed blade propeller turbine perform very poor below 80% of rated efficiency. While Pelton and axial flow turbines can directly be coupled to a generator, Francis and cross flow turbines are bulky and heavy and also operates at lower speed so they need a speed-up mechanism to drive a generator [16]. A comparative part flow efficiency of various turbine is shown in Figure 2.

Table 2: Turbine application based on head [9]

Turbine classification	Head classification		
	High head (>50 m)	Medium (10-50 m)	Low (<10 m)
Impulse	Pelton Multi-Jet Pelton Turgo	Multi Jet Pelton Crossflow Turgo	Crossflow
Reaction		Francis (spiral casing)	Francis (open-flume) Propeller Kaplan

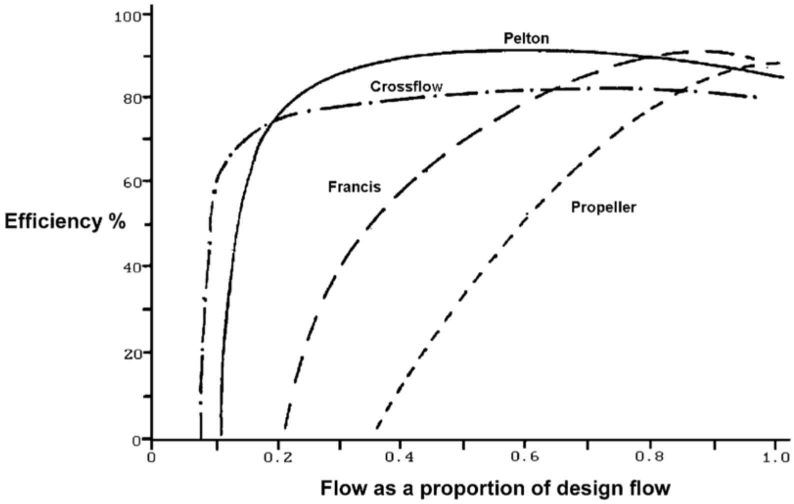

Figure 2: Part flow efficiency of various turbine [9]

2.2 Turbine selection criteria

The selection of the turbine suited for a particular site depends upon the site specifications specially head, discharge and, running speed of the generator. Figure 3 shows the basic turbine selection chart for various type of turbines. When a turbine has to be selected for other regions marked other than in the chart then they are selected on basis of specific speed. In such case Table 3 can provide a basic guideline on selection of turbine.

Turbine selection considerations

a) The overall cost of the installation for given power and head can be lowered by using a turbine of higher specific speed. Selection of turbine with higher specific speed reduces the size of the turbine [8], [17].
b) If a runner of high specific speed is selected for high head then the turbine requires higher mechanical strength which increases the cost of turbine
c) If a turbine of too low specific speed with low head is selected then due to the lower turbine speed the cost of the generator increases.

d) An increase in specific speed of the turbine comes along with the lower maximum efficiency and greater recovery from the draft tube. So while choosing higher specific speed turbine an additional cost of draft tube and foundation has to be considered.

Table 3: Turbine and their corresponding specific speed

Turbine type	Specific speed
Pelton	12-70
Francis	
a) High head	80-150
b) Medium head	150-250
c) Low head	250-400
Kaplan and Propeller	300-1000

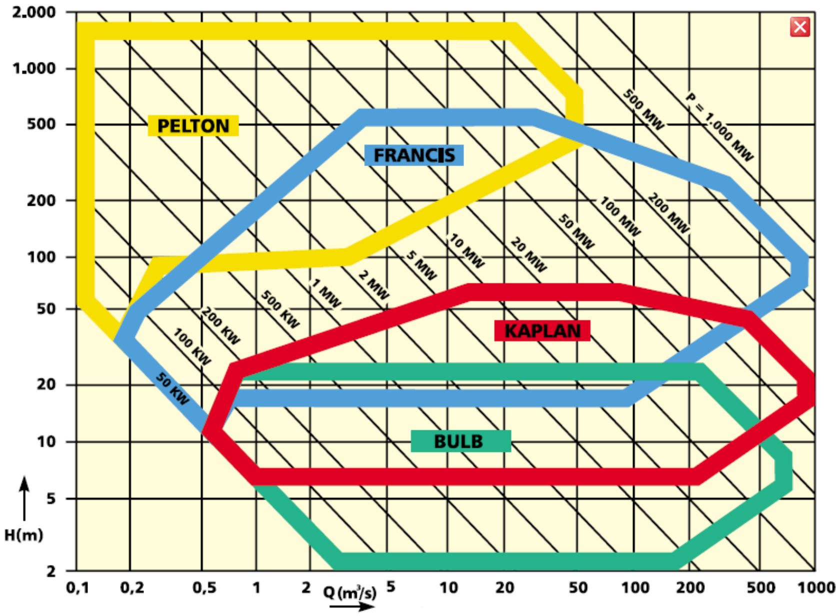

Figure 3: Turbine selection chart

CHAPTER -3

DESIGN OF PICO PROPELLER TURBINE

The major factors that are considered while manufacturing a pico turbine are listed below.

a) Low cost manufacturing is the first priority.
b) Self-contained and light enough to be carried by one or two people and withstand rough handling
c) Ease of installation as skilled labor are hard to find at rural areas

3.1 Design parameters

The turbine has been designed to generate around 300 W of electricity from a head of 2 meter and a flow rate of 30 l/s. The electricity thus generated is sufficient for a single house lighting purpose in developing countries where the grid energy is not present. Design guidelines by Nechleba [18] which has been cited widely by most of the researchers [8], [16], [19]–[26] and Simpsons and Williams [27]–[30] are followed for the design of the propeller turbine. Faulkner [21] has suggested using 3000 rpm generator is more stable in terms of maintaining speed so a generator with rated speed of 2500 and maximum speed of 3000 rpm has been chosen.

The design parameters considered for the design are tabulated below

Table 4: Basic parameters of the Site

Parameter	Symbol	Value	Unit
Head	H	2.5	Meters
Flow rate	Q	30	Liters per second
Total output efficiency	η	50%	
Theoretically Available power	$P = \eta \rho g Q H$	294	W
Generator Speed	n	2500	Rpm
Specific Speed	$N_s = n \frac{\sqrt{P}}{H^{5/4}}$	570	

3.2 Turbine selection

Beside the specific speed, turbine selection, especially in pico hydro, is also governed by the efficiency, constructability, cost, maintenance and serviceability, portability and, modularity of the system [31]. Impulse turbines like Pelton and Turgo are well developed and widely used in countries like Nepal and other developing countries as they have high design flow efficiency and can operate without seal under atmospheric conditions thereby reducing the risk of cavitation. They also offer higher partial flow efficiency. But when subjected to low head environment they demand for larger diameter thereby increasing the manufacturing and, maintenance cost.

Propeller turbine operates under low head with higher specific speed. Compared to Pelton and Turgo they require less number of blades. Also the blades are fixed which simplifies the manufacturing process. But the inherited disadvantages that comes with propeller turbine is that their part flow efficiency drops significantly if the flow falls below 80% of the design flow.

Francis turbine offers similar efficiency trends with propeller turbine but the geometry of the blade is complex and require high expertise during manufacturing. Kaplan turbine being similar to propeller turbine shows better part flow efficiency but it is complex because of the adjustability of the runner blade.

Although all the turbine types have their inherited benefits they have their own suitable environment of use where one turbine stands outs above other. However propeller turbine having ease of manufacturing with less level of expertise even at developing countries and their simpler design tempted us to choose propeller turbine for our project.

3.3 Runner design

The turbine runner is responsible for conversion of hydraulic energy to mechanical energy. The runner has 3-8 number of blades based on specific speed [27], [32]. In a propeller turbine, the runner blades are fixed and cannot change their position. The flow enters the runner through guide vanes and runner is fully immersed in water.

Blade geometry varies based on the flow rate and head it is designed to operate. The blades are designed on airfoil profile for efficient operation which makes the blade complex to manufacture using traditional methods due to their irregular shape.

The runner dimensions recommended by [33] for above site specification measures around 96.61 mm which is rounded to 97 mm. Using a 97 mm turbine runner also gives an additional benefit of using the easily available pipes for casing.

While determining the dimensions of the turbine, either the turbine internal diameter or the ratio of the internal to external diameter (D_h/D_t) can be treated as a variable. Hub to tip ratio defines the annulus flow area in the turbine and also defines the absolute fluid velocity through the annulus. Chica has suggested that the ratio D_h/D_t varies from be 30%-50%. In smaller turbine, smaller ratio of hub to tip indicates large twist in the blade. The hub to tip ratio differs on various literature Simpsons &William [27] has suggested to use larger hub to tip ratio. Nechleba [18] has suggested the ratio to be 0.3 for turbines operating below 5 m head, Park and Roh [34] has suggested it to be 0.5. Flaspoher [33] recommendation for the hub diameter is 34.8 mm but a little bit larger hub diameter has been selected to facilitate shaft hole and maintain the strength of the turbine.

The number of blades in the turbine also affects the overall performance of the turbine. With increase in number of blades the spaces decreases thereby increasing the flow guidance, however the losses due to friction decreases. Nechleba [18] has suggested using 3 blades in a turbine operating within head of 5m. While Simpsons and Williams [27] has recommended 5-6 blades. Alexander *et al.* [19] has suggested to use small number of blades to make the manufacturing easier. Four blade design as suggested by Ho-yan [8] was adopt for the turbine similar with commercially available power pal model and also to ease manufacturing.

Table 5: Hub tip ratio and number of blades

Design parameter	Symbol	Value
Hub to tip ratio	D_h/D_t	0.4
Number of blades	Z	4

3.4 Design velocity diagrams

The blade angles changes from leading to trailing edges as it should match with the relative flow angles at all radii. Thus the blades have complicated curvature. The axial flow velocity in a propeller turbine is constant so the angles at leading and trailing edges are determined by the change in the tangential velocity components.

Flow area between hub and tip $(A_f) = \pi(D_t - D_h)^2$ = 6133 mm^2 = 0.0061 m^3

Axial velocity $(C_m) = \dfrac{Q}{A_f}$ = 4.89 m/s

Theoretically axial turbines are assumed to have no whirl component of velocity at the exit *i.e.* C_{u2}. However the angle calculated by this method are different than the actual blades of the efficient turbines [27] Thus there are two different approaches while designing axial flow turbine. The first one is where the exit velocity is considered purely axial. Faulklner [21] has adopted this method for the blade design. The second approach assumes that there is a residual whirl component at the turbine exit. In this approach an isosceles exit velocity triangle is assumed i.e. W_2=U. The value of C_{u2} and inlet velocity triangle can be determined by using Braun's construction suggested by Nechleba [18]. Various literature has stated that this approached yield the higher overall efficiency but in case of small turbines it might give significant value of V_{w2} [27]. This approach is most widely used by various researchers including Simpsons and Williams [27], Nechleba [18], E. Chica *et. al.* [35]. But in our case the value of c_{u2} is significant so the first approach has been adopted.

Additionally, fillet has also been done in between the hub and blade region to increase the strength.

Table 6: Calculated parameters for turbine

Parameter	Symbol	Value	Unit
Constant	$v = \sqrt{2gH}$	6.26	m/s
Through flow area	$A = \frac{\pi}{4}(D_h - D_i)^2$	0.0061	m^2
Specific Inlet velocity to draft tube= Meridional velocity of runner	$c_s = \frac{Q}{A}$	0.781	
Angular speed	ω	261.8	Rad

In miniature sized turbine because of the manufacturing limitations, the blades are mostly constant thickness blades. But if we use a 3D printer then we can build a turbine with aero foil shape easily which helps in increasing the efficiency of turbine.

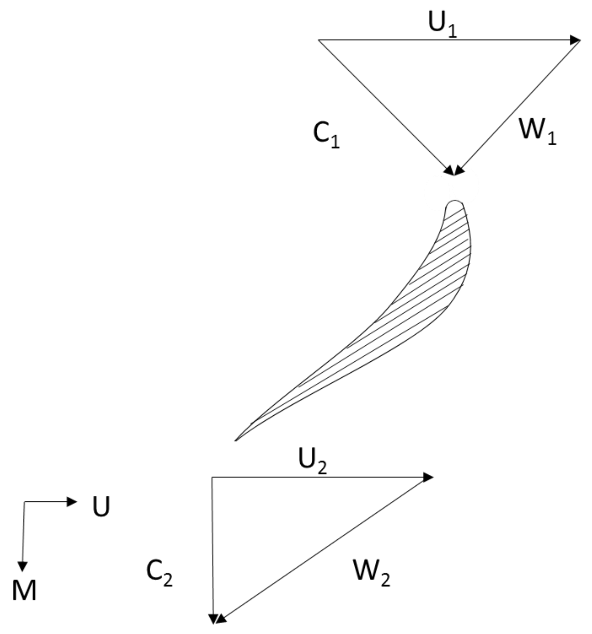

Figure 4: Velocity triangle at rotor inlet and exit

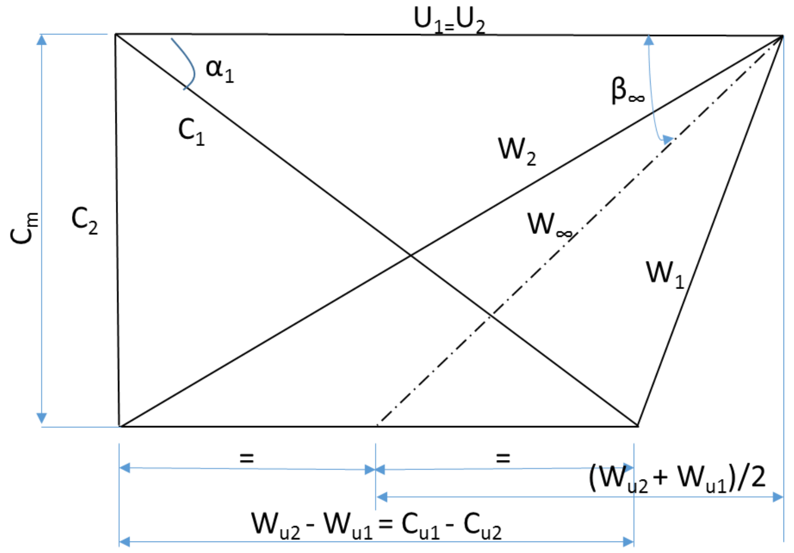

Figure 5: Combined velocity diagram

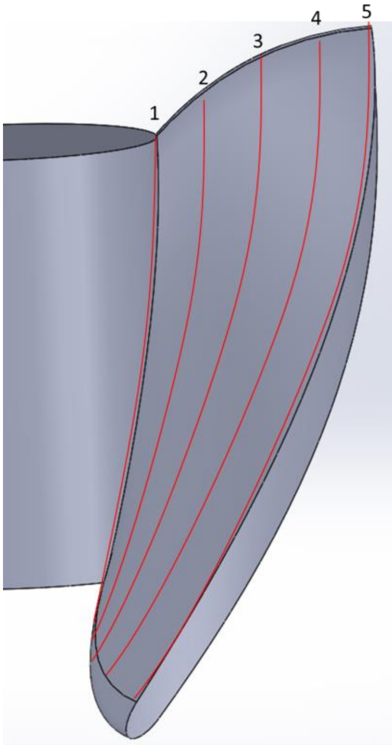

Figure 6: Radial sections of blade

Table 7: Blade angle calculation

Parameters	Symbol	Blade station					Units
		1= Hub	2	3 = Mean	4	5 = tip	
Diameter	D	0.04	0.054	0.069	0.083	0.097	m
Radius	R	0.02	0.027	0.034	0.041	0.0485	m
Hydraulic efficiency	η_h	0.71	0.76	0.76	0.76	0.71	-

Specific peripheral velocity	u1=u2	0.836	1.134	1.431	1.729	2.207	m/s
Specific meridional velocity	c_s	0.781	0.781	0.781	0.781	0.781	m/s
	c_{u1}	0.425	0.335	0.265	0.220	0.175	m/s
	w_{u1}	0.411	0.798	1.166	1.509	1.852	m/s
	w_{u2}	0.836	1.134	1.431	1.729	2.027	m/s
Relative inlet flow angle	β_1	56.4	35.1	26.2	20.9	17.6	Degree
Relative Outlet flow angle	β_2	26.9	22.3	19.0	16.5	14.6	Degree
	β_∞	52.6	39.5	31.2	25.8	21.96	Degree
Blade position	x	31.416	42.608	53.800	64.992	76.184	mm
Chord length						92	mm
l/x						1.2	

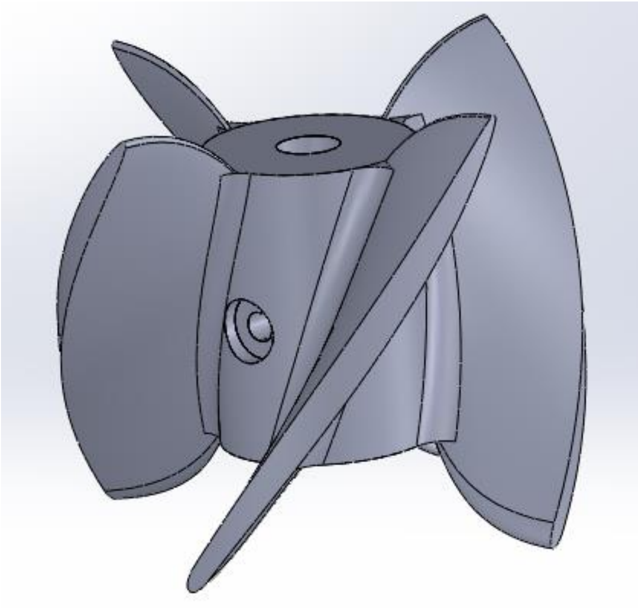

Figure 7: Cad Modelling of Runner

3.4.1 Forces acting on blade

a) Tangential force

Tangential force acting on the blade is defined as

$$F_t = \frac{P}{2\pi n z r_{cp}}$$

where, P is power, n is the rotational speed, z is the number of blades and r_{cp} is the radius of the center of pressure

and center of pressure (*r_{cp}*) is defined by $r_{cp} = \sqrt{\frac{R_t^2 - R_h^2}{2}}$.

The tangential force acting on the blade is 53 N.

b) Axial Force

Assuming that the blade is dormant plate, the axial force, F_a, can be calculated using

$F_a = \rho g H_n A_b$

where, A_b is the area of blade which is 1.363 x 10^{-3} m^2.

The axial force acting on the blade is 33.4 N.

c) Resulting force

Resulting force can be calculates using $F_r = \sqrt{F_t^2 + F_a^2}$

The resulting force acting on the blade is 62.6 N.

d) Centrifugal force

The blade weight causes the centrifugal force which is defined as

$F_c = M_b R_{cg} \omega^2$

where, M_b is the weight of the blade, R_{cg} is radius to the center of gravity and, ω is the angular speed.

Since the blade is constant thickness blade the center of gravity lies in between hub and the tip i.e. 68.5 mm.

The blade is 3mm thick with an area of 1.363 x 10^3 m^2, the weight of the blade can be found by multiplying the volume of the blade with the density of ABS from Table 9. Thus the weight of the blade is 4.29 grams.

3.5 Stator design

The stator has been designed to match the flow angles of the rotor. The system was simulated with a stator of 10 blades but the results on just runner and the draft tube were better confirming with the results of literature [19], [27].

3.6 Casing/ housing design

Various type of turbine casing design has been discussed in various literature. Most of them being spiral type which can provide the certain whirl before entering into the turbine. Most widely followed guideline is suggested by Nechleba [18] which suggests use of spiral pits for smaller turbines operating below 10 m head. Similar concept has been followed by Ho-yan [8] and commercial power pal models. Other researchers [19], [27], [36] has used spiral casing in axial flow turbine. Spiral casing provides necessary swirl to the turbine thus increases the efficiency but their construction and fabrication is difficult and expensive.

The housing for the turbine has been adopted from pump as turbine concept. An axial turbine with an elbow and axial guide vanes has been previously demonstrated in literature [16], [20]. Although this design has lower efficiency it has been adopted to reduce the significant cost of the installation.

3.7 Draft tube design

Draft tube is a cone which is used for recovering dynamic head from the runner outlet and also reduces the losses due to non-uniform flow in the tailrace. The draft tube has been designed based on the recommendation from Simpsons and Williams [27].

The conical length of the draft tube should be 4-10 times the diameter of runner so a length of 0.5 meter (which is 5 times the diameter) has been selected. A cone angle of 7^0 degree has been selected based on the results of [33]. The draft tube angle recommendation has been found different on different literatures. Simpsons and Williams [27] has suggested the cone angle to be 8-12 degrees.

Table 8: Draft tube specification

Draft tube specifications			
Parameter	Symbol	Value	Unit
Conical length	L	0.5	m
Angle from axis to wall	X	7	Degree
Outlet Velocity	C_4	0.791	m/s
Diameter at entrance of tube	D3	100	mm

CHAPTER - 4

EXPERIMENT, RESULTS AND MANUFACTURING STRATEGIES

ANSYS workbench with its fluid add-ons has been used for the design and simulation of the turbine rotor.

4.1 Simulation

Simulation has been carried out using ANSYS CFX. A separate static analysis has also been performed by importing the pressure result from ANSYS CFX. The result of the simulation and experiment are presented later on this section.

4.2 Efficiency

Advancement in CFD simulation has resulted higher efficiency in large hydraulic turbine but scaling down these turbine to fit for pico hydro applications are not advised as cost per kilowatt varies while decreasing size. Thus pico and micro hydro turbines are simplified at the expense of hydraulic efficiency to maintain the competitive cost with other energy sources [16].

In small sized turbine the use of guide vane increases the losses due to friction and furthermore the vegetation and leaves might get stuck in the guide/stay vanes which decreases the efficiency of the turbine and need frequent cleaning [26]. Thus the guide vane has been omitted from the setup. The efficiency obtained by simulation is 29.8%.

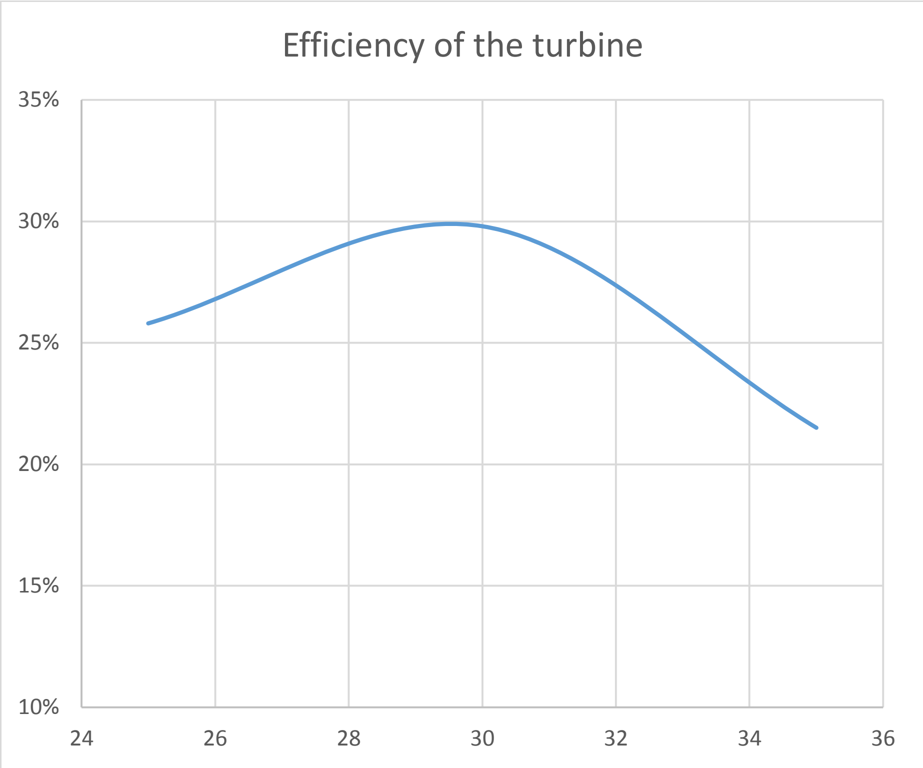

Figure 8: Efficiency of turbine

Overall efficiency of 40 % has been termed adequate by [21] who also designed a propeller turbine for 1 m^3 flow at 2.7 meter head. Demetriades *et al.* [16] have also studied about the axial and radial guide vane and has obtained efficiency of 33% in axial guide vane. They have stated the reason for lower efficiency to be 90 degree sharp bend. They also further suggested that the use of guide vane did not produce the desired result. Similar kind of result on use of guide vane has been demonstrated by Alexander *et al.* [19], [27]. In case of pico hydro systems the use of guide vane increases the risk of catching leaves and other vegetation which might lead into blockage. Removing the guide makes omits the tedious work of removing the vegetation daily [37].

4.3 Static Analysis of 3D printed turbine

One of the major question that arises with the 3D printed turbine is "Are they strong enough to hold the water pressure?" Therefore, we performed a static analysis using the pressure results from ANSYS CFX simulation, the result of which is shown in Figure 9&Figure 10.

Table 9: Physical Properties of ABS [38]

Material : ABS P400	
Physical properties	Value
Density	1060 kg/m3
Tensile strength, Ultimate	38.5 MPa
Tensile Strength, Yield	43.2 MPA
Young's modulus	2.4 GPA
Poisson's ratio	0.367

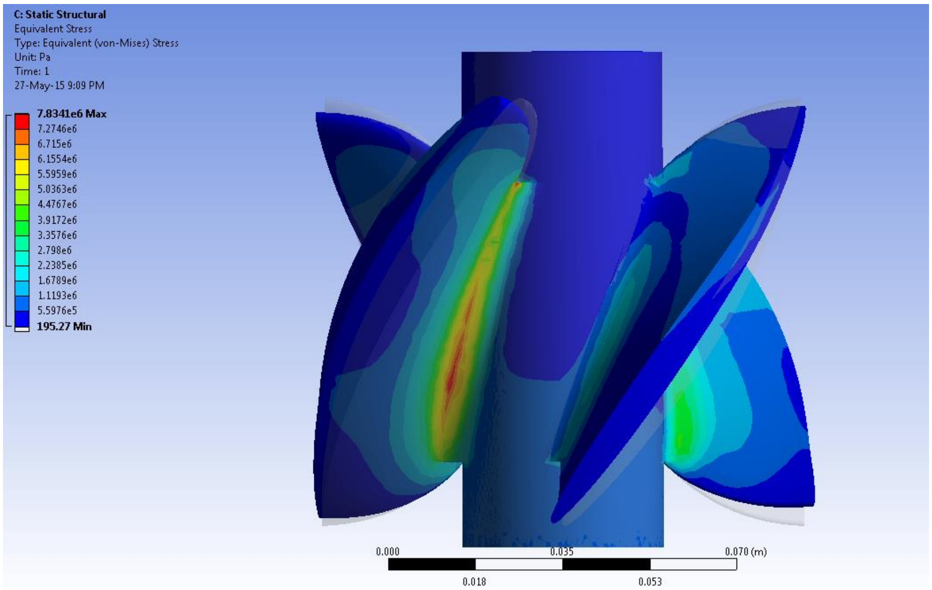

Figure 9: Static analysis of turbine (front view)

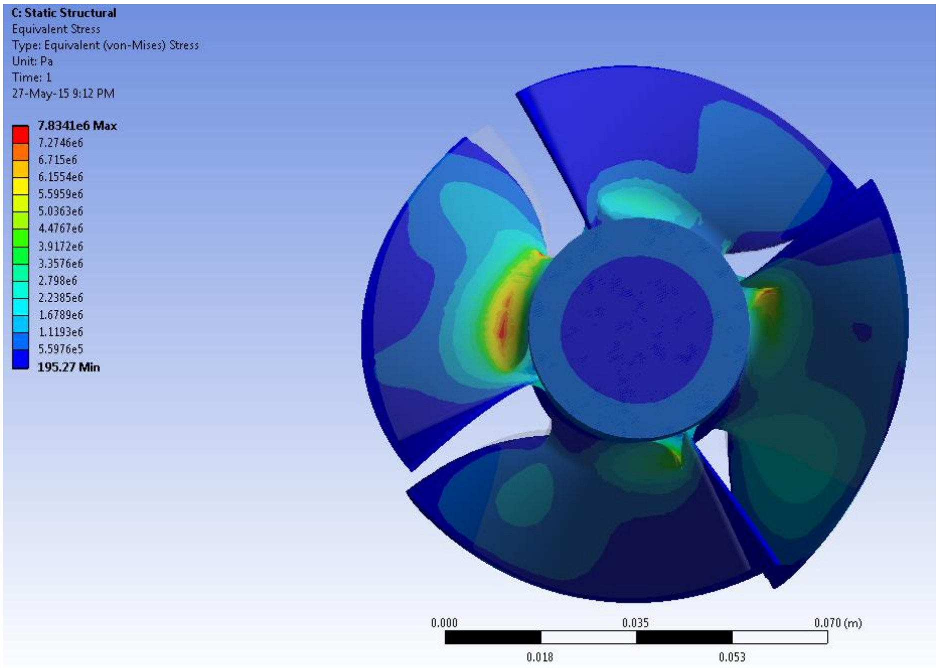

Figure 10: Static analysis of turbine (top view)

The static analysis shows that the maximum stress is 7.8 MPa. The material properties of FDM ABS is listed in Table 9. The strength of FDM ABS ranges from 60% to 72% of the strength of injection molded part of the same FDM material. The ultimate strength of the FDM ABS is 22.1 MPa [39] while the stress in the turbine is 7.8 MPa. Thus the 3D printed turbine can sustain the water pressure. It is also found that the pressure is concentrated in the hub-blade joint so fillet in that section should be done to increase strength.

4.4 Manufacturing strategies for 3D printed turbine

Compared to impulse turbine reaction turbines blades have more intrinsically profiled blades with carefully designed casing thus require sophisticated fabrication methods which has limited the attractiveness of these turbines in developing countries. However low heads sites are generally closer to the house, the interest in reaction turbines are increasing. [40]

a) Maintain a lower speed by making the turbine slightly larger than recommended dimensions would decrease the effect of cavitation.
b) Thicker blades increases risk of cavitation so blades should be as thin as possible maintaining the strength.
c) Using fillet in between the blade and the hub increases the strength of the blade
d) Epoxy coating on the 3D printed surface decreases the water affinity of the ABS and also increases the resistant to the sediments thereby increasing the life of the blade.

One of the major advantage of using 3D printer over casting is it is lot faster and relatively cheaper than traditional casting process. As the size of the turbine is site specific, sometimes we might get turbine that is larger than the size that the available 3D printer can print. Since a bigger dimension 3D printer is expensive, the advantage over casting fades as their cost becomes same. In such case the turbine can be printed in pieces and assembled and glued together. Following design and manufacturing strategies have been purposed for a 3D printed manufacturing turbine

a) If the whole portion of the turbine can be printed (in single piece) in the 3D printer then the turbine should be printed as a whole.
b) If the turbine can’t be printed as a whole then the turbine design can be divided in parts where the whole portion of the blade can printed. The printed parts can be assembled and glued together to form a single piece. The design concept for this strategy is shown in Figure 11 to Figure 13. The blade design is not disturbed in this design so the hydraulic efficiency is not affected much.

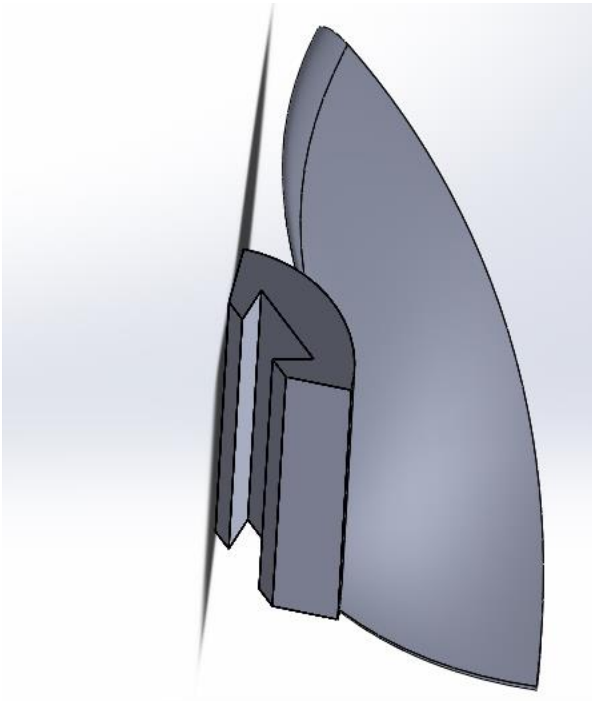

Figure 11: Design for printing individual blade for assembly

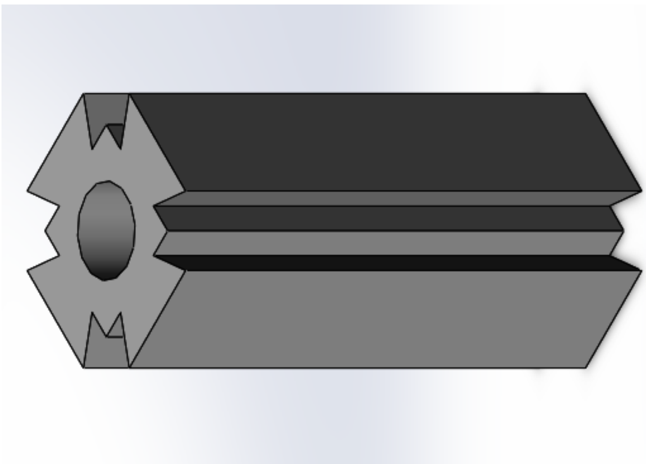

Figure 12: Design for support for assembly of individual printed turbine

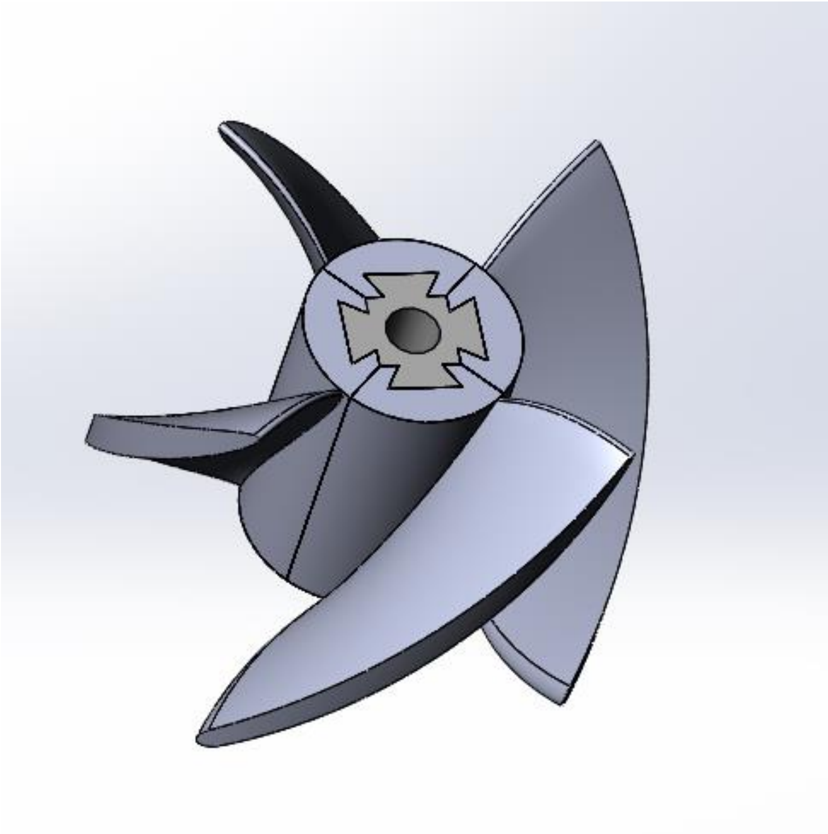

Figure 13: Assembly of individual printed blades

4.5 Installation

In order to test the performance of turbine we installed the system in Thanapati VDC of Nuwakot district, one of the affected area by earthquake in Nepal. Upon the testing of turbine the turbine didn't reach the designed speed. Which might be because of lack of flow rotating structure.

Figure 14: Installation of turbine at Thanapati VDC, Nepal

4.6 Advantages of 3D Printed turbines

Some of the major advantages that 3D printed turbines offer over conventional turbines are listed below.

a) 3D printed turbine can give almost same or better efficiency as the blade angles can be matched accurately.

b) Airfoil shape in turbine can be achieved easily which helps in efficiency increase

c) Easier and faster to manufacture.

d) Cheaper than conventional manufacturing process. A 3D printed turbine costs below $100.

4.7 Limitations of the 3D printed design

The limitations in 3D printed turbine are inherited because of the material properties of ABS. Compared to turbine manufactured by traditional ways, 3D printed turbine has following demerits.

a) Additional sedimentation removal method should be adopted for ideal operation condition.

b) ABS possess lower strength compared to metal turbines.

c) The life of ABS is lower compared to metal turbine. They have maximum life of 2 years [41].

4.8 Economics of 3D printed pico hydro turbine

3D printing is an additive manufacturing technology. As seen in Figure 15 the price of the 3D printer has fall drastically in last 10 years and the trend is still decreasing. Figure 16 shows the comparative price of traditional and additive manufacturing. 3D printed parts are always cheaper to manufacture than traditional method if a single piece has to be manufactured. Since turbine are custom tailored to match site specification and the turbine is unique for each site manufacturing by 3D printing will be the cheaper option compared to traditional manufacturing process.

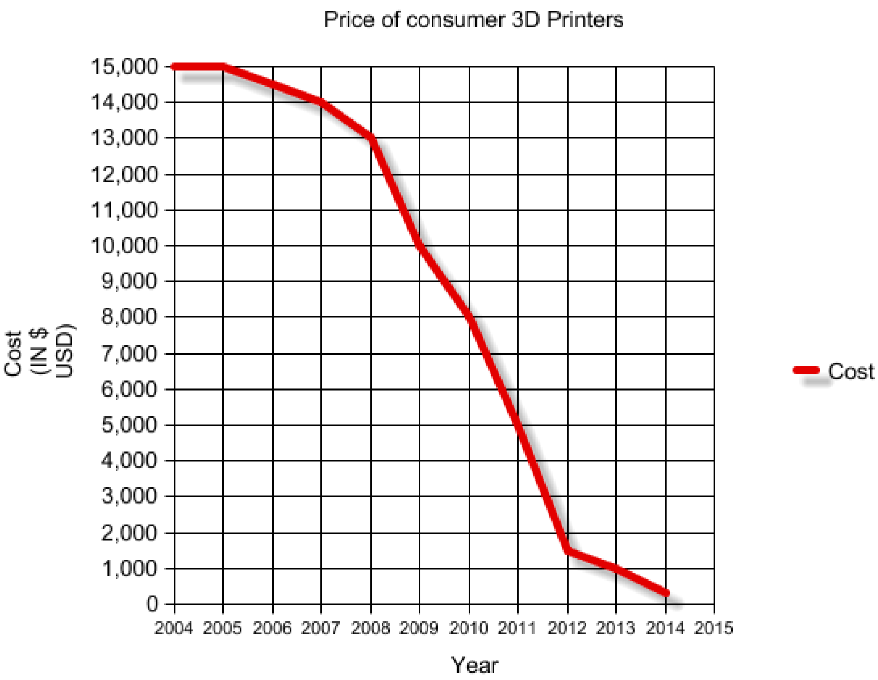

Figure 15: Price trend of 3D Printers [42]

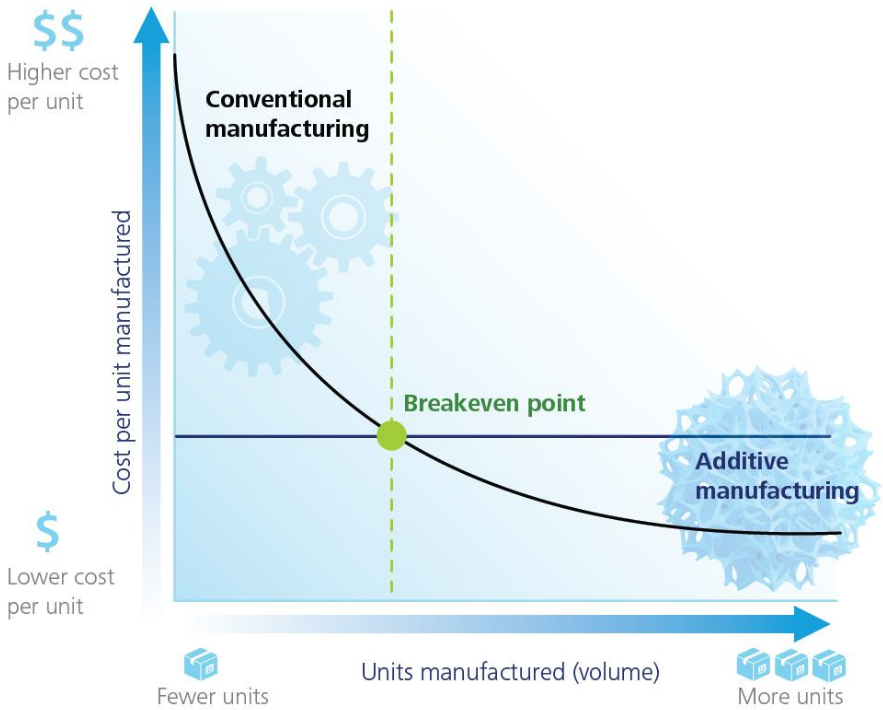

Figure 16: Breakeven analysis of conventional and additive manufacturing [43]

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Rural electrification has been identified as one of the vital tool for improving quality of life and decreasing the poverty. There are a lot of low head sites in developing countries which can be exploited for rural electrification. Traditional manufacturing process are expensive and time consuming. 3D printing technology is still in developing stage so the cost of the 3D printing is decreasing drastically. Using 3D printing technology not only decreases the cost but also decreases the time of manufacturing as well. Initial investment can be drastically decreased by using 3D printing technology which can make pico hydro technology accessible to the people with lower income level. Installing the 3D printed turbine the user can involve in income generating activity using electricity and replace the turbine with a casted one once they have enough money.

5.2 Recommendation

The turbine was installed in Nepal but the designed speed was not meet. Which is because of lack of flow rotating structure. Open flume design, spiral casing or use of flow rotating structure that can help in matching the angle of attack at inlet is suggested.

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초 록

제 3 세계 발전도상 나라에는 빈곤한 고립지역이 많이 있는데 이런 지역에는 기초시설도 많이 낙후하고 인구도 아주 희박하다. 후진 기초시설로 인한 국가 송전선망의 증축이 어렵지만 낮은 수원이 많기에 피코/마이크로 수력발전이 에너지 생산의 메인 옵션으로 활용될 수 있다. 그렇지만 피코/마이크로 수력발전 시스템을 구현하는데 있어서 터빈기술의 생산비용은 개발도상 나라들한테 아주 큰 병목중의 하나로 되고 있다. 터빈 제작에 필요한 비용을 줄이고자 본 연구에서는 3 차원 프린터 기술을 응용하여 터빈을 제작하려고 한다. 3 차원 프린터는 적절한 형상의 소형 터빈을 제작할 수 있으며 이는 이론적 효율과 매칭할 수 있게 된다. 때문에 3 차원 프린터를 이용하여 발전소자를 제작하고 발전도상국가에서 조립하여 사용하게 되면 엄청난 비용을 절감시킬 수 있다. 본 연구의 목적은 2.5m 높이와 30lps 유량으로 300W 의 전력을 제공할 수 있는 저비용 프로펠러 터빈을 설계하고 제작하는 것이며 300W 의 전력은 제 3 세계 발전도상 국가에서 한 가족의 전력 소비를 충분히 만족시킬 수 있다.

Keyword: 미소수력, 프로펠러 터빈, 축류 터빈, 3D 프린팅

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