Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 3 Issue 3, March - 2016

Development and Evaluation of Water Powered Machine for Rural Electrification and Flour Milling in Oromia, Ethiopia

Gemechis Tesema
Soil and Water Engineering Research Case Team
Bako Agricultural Engineering Research Center, BAERC
Adama, Ethiopia
tesema2010@gmail.com

Merga Workesa
Soil and Water Engineering Research Case Team
Bako Agricultural Engineering Research Center, BAERC
Bako, Ethiopia
mwarkesa@yahoo.com

Abstract: **Rural environments represent different electrification needs compared with the urban and industrialized areas as covering the scattered rural community under national grid system is costly. Such particularism implies that rethinking on alternatives for rural electrification such as Micro-hydropower is required. Micro-hydropower represents an interesting feature for remotely or sparsely populated rural areas. This paper presents effort enacted in Western Oromia to develop and evaluate the water powered machine for flour milling and rural electrification. In doing so, Gibe River near Bako town, gauged station stream flow of 10 (1996-2006) was collected. The collected was data was checked for consistency or dependability. Design discharge was generated from data (0.12m^3/s) with gross head of 10.61m. After assessing environmental impact the project, water powered machines' parts required for flour milling and electricity generation were designed, manufactured and installed. Lined cable of 6mm thickness was extended from the plant to rural household which was 1.5-2km far from the plant to rural households. The water powered machine was tested to serve both milling and electrification alternatively with output of 250 kg/hr and 330V on average base day and night respectively.**

Keywords—potential; design; water powered machine; flour milling

I. INTRODUCTION

Energy is obligatory input for most production processes, and other economic activities; therefore, it is essential component of human life. Ethiopia has important natural resources like Rivers. Therefore, strongly cultivating it's still very limited energy supply especially in rural area requires inventing available hydropower potentials and developing through different options like micro, mini, small, medium, large hydropower is binding [1]. Hydroelectricity is derived from the power harnessed flow of falling water, typically from fast flowing streams and rivers.

In a hydropower system, the energy which exists in water is converted into mechanical or electrical energy by hydro-power system. Generic hydro power systems can be categorized in many different ways. Some of the methods of classification are based on how the electricity is generated by the plant, what kind of grid system is utilized for the distribution of electricity, the type of load capacity and the type of storage used by the system [2].

Generally, hydropower plants (HPP) generating less than 100kW of electricity are termed as micro HPP; those generating 100 to 1000 kW are termed as mini HPP; those anywhere between 1 MW to 10 MW are termed as small HPP; between 10 MW to 300 MW are termed as medium HPP and those with the power generating greater than 300 10 MW are termed as large HPP. Although variations in definitions exist; this is the most commonly accepted definition [3]. Based on the type of grid system, hydro power plants can be classified into local grid and extensive grid systems [4].

In the local grid system, the electricity is generated and distributed only for the small locality, without use of any sophisticated electromechanical distribution systems. In contrast, in an extensive grid system, the electricity generated by the HPP (Hydro Power Plant) is loaded in a form of extensive grid such as the national grid system.

In hilly area water mills, have significant role in utilization of mechanical power from water streams, mainly for milling purpose. In Ethiopia, a large potential for Microhydropower plants in areas which are remote to the national grid; but close to rural house hold to exist. Figuratively more than 600 traditional hydro-mills that could be used for hydropower have been identified. A database of hydropower resources and potential sites is being set up by the national Government.

Hydropower requires source to be fairly close to the site of power usage or to the national grid. The turbine converts potential energy stored in the flow of water to produce electricity. The same water head used for watermill or milling grain can be used for hydroelectricity. Small-scale hydro is a useful way of providing power to houses, workshops or villages that need an independent supply.

Oromia Regional state is favored in natural setup having plenty of useable water resources as the region is characterized by high plateau and very limited lowland areas. The altitude of the region ranges from below 500masl at the rift to 4377masl at mountain [5]. Considerable unexploited hydropower potential exists in Oromia at the small to micro-scale level. The electricity generated can potentially be supplied to the local community.

Therefore; in the region, principally, the use of watermill or rural hydroelectric power is industrious.

In order to boost the small hydropower capacity in the region, improvements can be made in the following areas:

i. Despite a long history of micro-hydropower in Ethiopia, local skills to manufacture, operate and maintain the plants are not well developed.

ii. The schemes built in the 1940s were fully controlled and managed by foreign experts.

Small and micro-hydropower equipment and components are not available off-the-shelf in local market. Relatively low return on investment is currently discouraging individual private investment in small hydropower, but cooperatives with members that will benefit from getting access to electricity may be potential developers, since their primary motive is not return on investment.

Competitive water uses and demand may prevent small hydropower development. An increasing population could create more demand for water by upstream users. Therefore such a research is mandatory to bring required technological transformation though exposure beyond improving life style of rural society.

Therefore in this paper, attempt was conducted with the objective of developing water powered machine for milling flour and rural electrification by shift day for electricity and flour milling at day and evaluating the machine for both purposes.

II. Material and Method

In the process of designing, material selection, prototype production, installation and evaluation of water powered machine for flour milling and rural electrification at Bila, Western Oromia, Ethiopia on Gibe River, the following procedures were followed.

1. *Alternator of the Microhydropower System*

This type of MHS is designed to supply the load directly, as it does not use battery as storage. Therefore, alternator is directly connected through three phase electric cable of thickness 6mm to the user's house. No governor is suited to the system, but breaker at control points.This is the most common system that can be found in normal use and is most suitable for grid connected sites and remote standalone sites. The smallest available fully integrated system of this kind is 200W which can work with the head [4].

2. *Grid Connected*

If there is already a grid supply available, it is possible to still install the water powered machine and connect to the available grid system and obtain electrical power. It is possible to supply the excess power generated from MHS (Micro Hydropower System) to the grid through "net metering"[8].But if the system produce small power, high quality cable with small diameter should be used and therefore standalone system was used.

3. *Civil Work Components*

Intake is the primary means of conveyance of water from the source of water in required quantity towards the waterways of HPP (Hydro Power Project). Intake could be of side intake type or the bottom intake type. Usually, trash racks or filters have to be placed at the intake which acts as the filter to prevent large water born objects to enter the waterway of the MHP (Micro Hydro Project) [9].

4. *Headrace Canal and Settling Basin*

Once the water enters through the intake, the headrace canal conveys the water to the forebay. In order to reduce the sediment density, which has negative impact to other components of the MHS (Micro Hydropower System) specially turbine, de-sanding basins are used to capture sediments by letting the particles settle by reducing the speed of the water and clearing them out before they enter the canal. Therefore, they are usually built at the head of the canal. They are equipped with gate valves for flushing the settled undesirable sediments. De-sanding basin is capable of settling particles above 0.2-0.3 mm of size [9].

5. *Spillway and Forebay Tank*

Spillways need to be designed to remove the excess water due to floods, in order to minimize the adverse effects to the other components of the MHS (Microhydropower System). Spillways are often constructed in de-sanding basin and the forebay, from which the excess water is safely diverted to the water source.

Forebay tank is basically a pool at the end of headrace canal from which the penstock pipe draws the water. The main purpose of the Forebay is to reduce entry of air into the penstock pipe, which in turn could cause cavitation (explosion of the trapped air bubbles under high pressure) of both penstock pipes and the turbine [10].

6. *Penstock Pipes*

Penstock pipes are basically close conduct pipes that helps to convey the water from the forebay tank to the turbine. It is one of the most important components of the MHS (Micro Hydropower System) because it is at this point that the potential energy of the water is converted into kinetic energy. The velocity of water at the penstock is typically 3m/s and is often located at a slope over 45 degrees [11].

7. *Cross type Turbine*

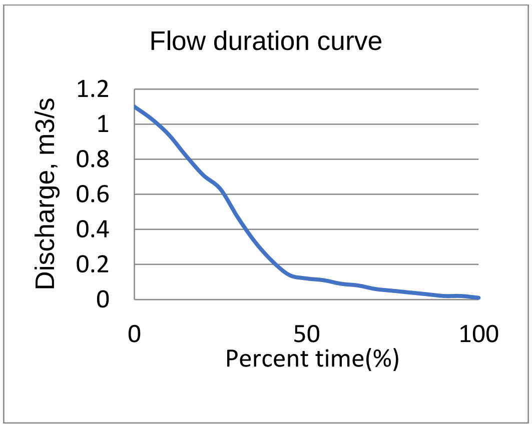
It is at this stage that the conversion of mechanical energy of water into electrical energy takes place. In a MHS (Micro Hydropower System) hydraulic turbine is the primary component which converts the energy of the flowing water into mechanical energy through the rotation of the runner [7].

Design of the machine parts were conducted thoroughly starting from gross head to determining shaft diameter. It includes a number of formula and calculations.

II. RESULTS AND DISCUSSION

1. Flow-duration curve

The flow-duration curve is specified by twenty-one values Q_0, $Q_{5\ldots}$, Q_{100} representing the flow on the flow-duration curve in 5% increments. In other words, Q_n represents the flow that is equaled or exceeded *n* % of the time. The graphical presentation flow duration which helps to select dependable design discharge rate was displayed in figure 1. Discharge for design is selected at 50% equaled is (Q_{des}) = 0.12 m^3/s.



1. Flow duration curve

2. Gross waterfall in the study area

Gross head determination is one of the parameters, required to design needed to design a MHS (Micro Hydropower Systems).These parameters will be utilized at a later stage while designing the case micro hydro system.

In western Oromia, investigation of potential site for micro-hydropower generation was conducted being aided by GPS technologies to measure displacement of the plant to the end users or rural community. Water head and displacement the plant to rural community were used as key determinant in the process of selecting potential site and accessibility is as well.

The head is defined as the vertical height in meters from the level where the water enters the penstock to the level where the water leaves the turbine housing. Water level, staff and rope is used to calculate the "head" during the field survey.

Table1.Summarized information gross waterfall

	Foresight (cm)	Difference (cm)
P1	28	
P2	190	162
P3	160	145
P4	182	167
P5	182.5	167.5
P6	195	180
P6	80	65
P7	160	145
P8	145	115
P9	-26	Net H= 10.61m

3. Design parameters and Manufacturing

In this specific site basically the flour milling part(forward moving belt) is designed and installed years ago while the part required for electrification (backward moving belt) were designed, manufactured and installed. For design purpose over all parameters parts were considered and summarized in the table 2.

Table 2. Design parameters

1	Gross head	10.61m (table 4.1)
2	Net head	$H_{rest} = H_g - h_f = (10.61-0.62)=10m$
3	Efficiency of turbine	$\eta_t = \frac{P_{output}}{P_{input}} * 100$
4	Synchronous generator of 1500 rpm & pulley and belt, 3:1 speed ratio and turbine angular speed, N=1500/3=500rpm	
5	Turbine outer diameter (D_o)	$D_o = 38.44 \frac{\sqrt{H_n}}{N}$ =26.22cm
6	Velocity of water at nozzle exit	$C_1 = c\sqrt{2gH_n}$ = 14m/s
7	Runner or blade velocity u	$u = \frac{2\pi N D_o}{120}$ =6.85m/s
8	blade spacing (t_b)	$t_b = \frac{kD_o}{\sin\beta}$, k is constant (0.087) &β is 39^0, t_b= 3.44cm
9	Area and thickness of jet (t_j)	$t_j = 11.7 \frac{\sqrt{H_n}}{N}$ =2.16cm
10	Blade number(n)	$n = \frac{\pi D_o}{t_b}$ = 20
11	Radius blade curve(ρ_c)	$\rho_c = 0.173 D_o$ =4.20cm

4. Design of poly and belt system (velocity diagram)

The special importance of cross turbine is that it is has two points of action, strictly speaking water act on the runner at the first stage and second stage as indicated on velocity diagram.The absolute velocity (C), The relative velocity(w), the peripheral velocity(u), angle between relative velocity and peripheral velocity or angle between the tangent of the blade and runner periphery (β), and α- attack angle (α) on the other hand, Subscript 1, 2, 3, 4, and 5 stand for Water entering the first stage, Water leaving the first stage Water entering the second stage, Water leaving the runner and, Entrained water leaving the runner respectively(fig2).

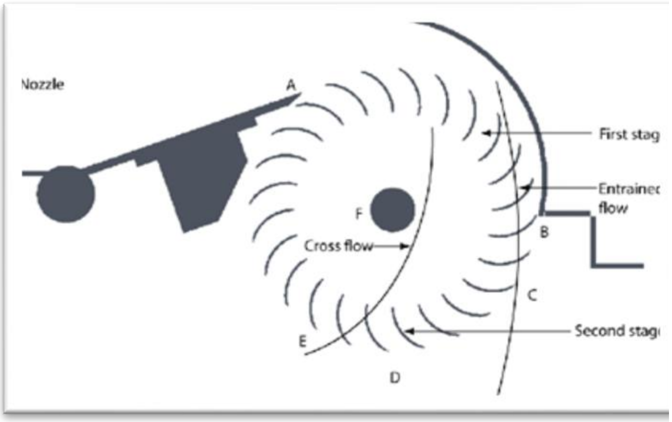


Fig. 2. Velocity diagram (Fay and Durgins, 2004)

From equation 6, Velocity of water (C_1) = 13.75m/s, from equation 7, blade velocity (u_1) = u_4 = 6.85m/s, blade velocity (u_2) = u_3 = 4.67m/s. It refers to inner diameter of disk.

$ta\beta_{1=}(2\tan 18)^{-1} = 33^0 \beta_1 = 2tan\alpha_1$ Since $\alpha_1 = 18^0$

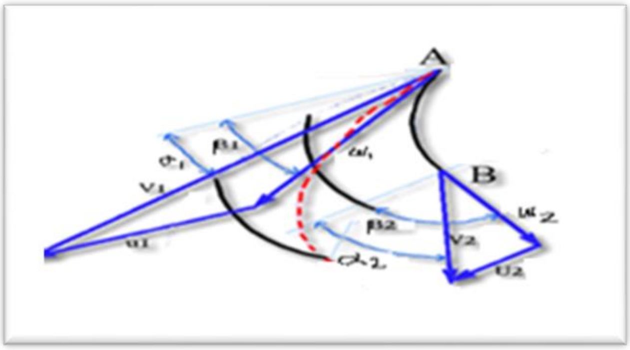


Figure 3. Velocity diagram of first stage

From velocity diagram (figure 3);

1). $w_1 = \frac{V_1 cos\alpha_1 - u_1}{cos\beta_1}$ w_1 = 7.4 m/s and $\beta_2 = 90^0$

2). $w_1^2 - w_2^2 = u_1^2 - u_2^2$ w_2 = 5.44m/s

Absolute velocity at exit of first stage:

3). $C_2 = (u_2^2 + w_2^2)^{0.5} = 7.17m/s$

Blade velocity at inner radius

4). $$u_2 = \frac{\pi N D_{inner}}{60} = \frac{\pi * 500 * 0.1783}{60} = \frac{4.67m}{s} \boldsymbol{tan\alpha_2} = \frac{\boldsymbol{w_2}}{\boldsymbol{u_2}}$$

and$\alpha_2 = \tan^{-1}\frac{5.44}{4.67} = 50^0$

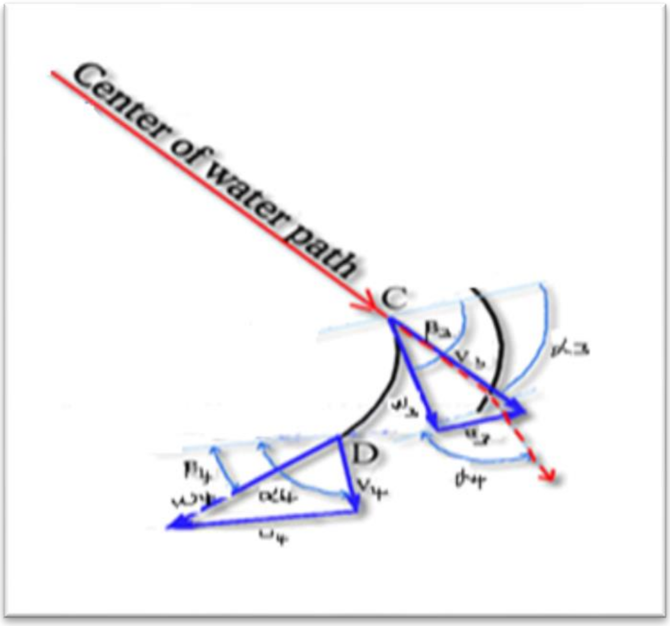


Figure 4. Velocity diagram of 2nd stage

Absolute velocity at inlet to 2nd stage

5).$C_3 = C_2 + \sqrt{2gD_{inner}}$

$C_3 = 7.17 + \sqrt{2 * 9.81 * 0.1783}$ C_3 = 9.04m/s

Blade velocity at inlet to 2nd stage is:

6).$u_3 = \frac{\pi N D_{inner}}{60} u_3$

7). $w_3 = \sqrt[2]{C_3^2 - u_3^2} = 7.74m/s$

8). $\alpha_3 = \tan^{-1}(\frac{w_3}{u_3}) = 60^0$

Relative velocity at exit of 2nd stage:

9). $w_4 = \Psi w_1$where$\Psi = 0.98$;

$w_4 = 0.98 * 7.4 = 7.25\frac{m}{s}$andby sim: β1= β_4 = 33^0

From triangular similarity:

$sin\alpha_4 C_4 = \sin\beta_4 w_4$;

$$w_4 cos\beta_4 = C_4 cos\alpha_4 + u_4 tan\alpha_4 = \frac{3.94}{0.77}$$

$\alpha_4 = \tan^{-1}(\frac{3.94}{0.77}) = 77.2^0andsin\alpha_4 C_4 = \sin\beta_4 w_4$

Therefore $C_4 = \frac{\sin\beta_4 w_4}{\sin\alpha_4} = 4.03m/s$

Belt and Pulley selection:

Turbine shaft speed, N = 500rpm; generator shaft speed, N = 1500rpm Speed ratio = 3 and turbine power = 10.12kw

10). Torque at generator $= \frac{p*60}{2\pi N} = \frac{9.72*1000*60}{2\pi*1500} = 64.43Nm$

11). Design power for belts = $p_{out} * factor = 9.72kw * 1.18 * 1.2 = 13.8kw$ and1500rpm SPB type belt is selected.

Pulley selection:

Minimum pulley diameter using 14.33kw at 1500rpm = 140mm from selected (standard table).

Larger pulley diameter = $3 * 140mm = 420mm$ standard pulley = 450mm and approximated center(c) = $D_{larger} + D_{smaller} = (450 + 140)mm = 590mm$

12). Belt length = $2c + \frac{\pi(D_L - D_S)}{2} + \frac{D_L - D_S}{4c} = 1707.67mm.$

Therefore the corrected belt length becomes = 1956mm with 1.05 correction factors.

Basic power per belt from power rating table diameter 140mm at 1500rpm and Power per belt = $7.09 \frac{kw}{belt}$,

Speed ratio power increment by interpolation

$= 1.21 \frac{kw}{belt}$and

Corrected power per belt = $(7.09 + 1.21) * 1.05 = 9 \frac{kw}{belt}$

13). Number of belts = $\frac{\textbf{Design}\, power}{power\ per\ belt} = \frac{14.33}{9} = 1.6 \sim 2$so, two belts are required.

Belt tension, $T_o = 32pN$ where N- no of belt = 2 &

P- Force to degrees belt 16mm per meter span = 65N from table. $T_o = 32pN$ =32*65*2 = 4160N

Belt speed:

140mm diameter of pulley at 1500rpm gives

14). Belt speed = $\frac{ND_S\pi}{60} = 11.02 \frac{m}{s}$ Belt width = $\frac{p_{outMF}}{p*60}$ =110mm

Calculation of shaft diameter

15). Belt tension = 4160N= 4.16kN $\omega = \frac{2\pi * 500}{60} = 52.36 \frac{rad}{s}$

After designing, manufacturing and purchasing all required components of the machine, installation took place and successfully tested. During evaluation phase, the so called water powered machine produced 330V of power on average base and able mill 250kg/hr of flour.

Recently 15 household are using both for flour milling and electrification. They are using machine for flour milling during day and for electrification in night. The electrical power it produces and mechanical power it delivers to grind flour depend up on discharge rate, water head, the capacity of alternator and turbine.

Therefore future research should aim to improve turbine, and uses of the gear box to increase output power with affordable power governor to boost the return from the project.

Figure 4.1 picture installed machine

V. Recommendation

The technologies is very important and life changing. But its cost makes it difficult for multiplication. Therefore sufficient feasibility study should be conducted before the formulation multiplication proposal and it important upgrade the technologies to make more viable.

V. REFERENCE

[1] Bhattarai, D. N. (2005). Hydropower Development in Nepal: A study of Demand forElectricity and FinancialRequirement up to 2030. DeviKumariBhattarai.

[2] Pandey,B. (2006). Micro Hydro System Design. Wordpress (www. binodpandey.wordpress. com).

[4] Hydraulic Energy Program et al. (2004). Micro-Hydropower Systems: A Buyer's Guide. Her Majesty the Queen in Right of Canada.

[7] Simoes, M. G. (2004). Renewable Energy Systems, Design and Analysis withInduction Generators. CRC Press.

[8] Greacen, C. E. (2004). The Marginalization of “Small is Beautiful”: Micro- hydroelectricity, Common Property, and the Politics of Rural Electricity Provision in Thailand. Berkeley: University of California.

[9] Harper, G. D. (December 2011). Planning and Installing Micro Hydro Systems: A Guide forInstallers, Architects and Engineers. Earthscan Publications Ltd.

[10] Masters, G. M. (2004). Renewable and Efficient Electric Power Systems.

[11] Sanchez, T. ;& Rodriguez, L. (June 2011). Designing andBuilding Mini and MicroHydro Power Schemes: APractical Guide. Practical Action.