DESIGN AND MANUFACTURING OF CROSS-FLOW TURBINE TO POWER COFFEE PROCESSING PLANT & NEARBY COMMUNITY VILLAGE IN KAFFA ZONE

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Abstract

Hydro energy, a well-studied form of energy, takes the lions share in energy generation. Lately, it has become evident that the power generated at large scale hydro power plants will not be cost-effective for electrification of small rural villages located remarkably far from the grid lines. Thus, huge sum of money is required for the extension of major grid lines to small rural and scattered settlement settings, which in turn has created a large opportunity for more research and development in the area of micro hydro power plants development. This paper encompasses the study and analysis of the hydrology of a location found in the kaffa area of the SNNPR in Ethiopia including the corresponding design and manufacture of a cross flow turbine for the area to generate power that would be accessed by the local village and coffee processing plant. The plant is able to generate 19.39 KW's of energy with an approximate efficiency of 80 % which can light up to 152 households assuming a 3hour usage per day including powering a pulping machine with an average working duration of 8hours per day. The design initiating from the hydrological study has covered design of the runner, shaft, nozzle and belt including selection of alternator and control unit. Moreover, the absence of a clear and simple design manual for the design of this machine has inspired the research for the development of a computer program that would simplify the designing process for professionals working on cross flow turbines.

Key words: Micro hydro power plant, Cross flow turbine, Turbine.

1. INTRODUCTION

1.1. General Background

Ethiopia stands as one of the most water rich nations in the horn of Africa. The government has already come up with a strategy to utilize this energy in its long term plan of making the country one of the largest hydro energy producers in Africa (Web-1). There are a total of fifteen hydro power plants in the nation, including the much acclaimed Grand Renaissance Dam, out of which thirteen are fully operational (United Nations Industrial Development Organization (UNIDO) & International Center on Small Hydro Power (ICSHP), 2013).

It's important to note that these large scale hydro power plants constitute the largest share of the country's energy consumption. But it has become evident that stretching this to small rural communities with huge surplus but comparatively costly gridlines is getting to be a road block for the development of these areas. Although highly utilized in countries like china where 19,000 MW of electricity is harnessed from a total of 43,000 small hydro power facilities, Micro hydro power plants are still infant in Africa where the total theoretical potential per year is 1750 TWH, out of which the percentage of small hydro power plants takes a share of 1.59 with respect to the large hydro power plants (Gupta M, 2012). Looking onto the ample off-grid hydro energy potential of the nation, the government of Ethiopia has decided to build small hydro power plants of differing capacities at different regions around the country. However, the progress has been rather sluggish as compared to the many mega hydro power plants being built around the clock. One of the many identified regions for the development of small hydro power plants is the SNNPR (Web-2).

Amesha Mechata is a Kebele in the SNNPR located inside the Kaffa Zone, Bitta Woreda approximately 575 km's south west of the capital Addis Ababa. As a tropical setting with an expected high rainfall and sloppy topography, there are a number of streams that collect to make the locally known Menu River. The river has a very high discharge in the months May to September, decreasing accordingly in both directions during the months otherwise. Using Menu River, the high demand for electricity in Amesha

Mechata Kebele could be met through the provision of small hydropower development for households, health centers, schools, commercial and social activities, and/or other mechanical equipment. Moreover, the Kaffa Zone in general and Bitta Wereda in particular are known for its large coffee farms and correspondingly one of the largest coffee production areas in the nation. Since the Amesha Mechata Kebele in the region has no accesses to electricity, the coffee plant in that Kebele uses Diesel driven generator. In this background, the development of the small hydropower plant in that region also avoids loss of foreign currency for the purchase of conventional energy source such as diesel oil.

Furthermore, the development of such micro hydropower projects plays an important role in the conservation fauna and the environment in general. The possibility of usage of other cooking methods powered by electrical power abruptly reduces the destruction of large forestry.

2. CROSS FLOW TURBINE

The Cross flow turbine is family of the pelton turbine which is majorly composed of two major parts, the runner and the nozzle. The nozzle is responsible for allowing the water into the runner at a certain attack angle while the runner being a circular rotor is responsible for being hit by the jet of water entering through the nozzle and directly rotating the shaft to which the pulley driving the belt coupled to the generator shaft. The runner has two side walls to which the blades are fixed along the periphery of the turbine. The cross-section of the blades is circular with a certain radius of curvature. The water jet moving at an angle to the runner hits the blades on the first stage, passes across the center of the runner and hits the second set of blades, thus second stage. Its simple design, manufacturability and maintainability make cross flow turbine the ideal choice for local micro hydro power plant developments. Moreover, it works for wide range of head and discharge, ranging from 4 to 200 meters of net head and 0.04 to 5 m^3 /s (Web-3). Any plant that is able to generate power up to 100KW's is categorized under the micro stage. As the total power produced by cross flow turbine in this project is approximately 19 KW's, it can be classified under this group.

3. PROBLEM STATEMENT

As electricity stands as a vital and basic factor in the development of a region, increasing the number of off-grid power supply in rural areas play an important role in the socio-economic growth of a nation. And small & Micro hydro projects are highly being considered the new path for meeting the power demand in rural areas. The mere fact that small patches of households and villages suffice in these regions narrows the solution down to looking for easy, affordable and locally available materials and machines. And this calls for relatively simple design, manufacturing and installation coupled with spares that could be easily made available.

The absence of dependable design manuals plays a great role in the infant state of the development of micro hydropower plants. Additionally, the few designed, manufactured and installed turbines have shown a number of faults in minimal time requiring high amount of maintenance cost due to direct adoption of existing empirical formulas of large scale hydro power plants and poor material selection. Moreover, the lack of simple and specific design software that can be used as an assisting program that would enable designers to come up with important figures for analysis and manufacturing of cross flow turbines tackles the anticipated development of this study area.

4. METHODOLOGY

Papers written concerning the project have been read, scientific journals, articles and related studies have been gone through in order to find porous areas that need more research and the corresponding review presented an understanding of the technology and the components in a micro hydro power plant including the mechanical element responsible for the power generation.

Figure 1 Catchment area of location

Figure 2 Menu River

A site visit and selection has been undertaken and a 15 year rainfall data of the location has been received from the nearest meteorology station. Adding to this, catchment area of the location has been cropped out in order to come up with the seasonally varying flow rate and develop the flow duration curve which would consequently assist the load selection criteria. Existing empirical relations were used to come up with figures for the design of the different components of the turbine, which was followed by the drawing of each and every components of the machine. Moreover, material selection and stress analysis of highly vulnerable components were selected and tested accordingly using SOLIDWORKS design software. Then, the procedure gave way to the manufacturing process, where bill of quantities was first prepared and purchases undertaken. The final stage of the study was to develop a program that would assist the usually time consuming design procedure of the machine. Visual studio was used to create a c sharp based program. The software developed comprises the design of every component of the turbine with possible approximations including the development of flow duration curve.

5. LITERATURE REVIEW

Electricity is a vital commodity that plays an important role in the socio-economic development of a society. It stands as one of the indicator in defining the living standard, health and educational status of a community. According to World Bank, electric power consumption (kWh per capita) in Ethiopia stands at 51.96 in 2011 compared to USA who stood at 13,246 KWh per capita on the same year. However, access to it on rural areas has continued to be difficult in many African countries due to different reasons, cost being one of them (Web-1).

Over the last few decades, there has been a growing realization that in developing countries a micro hydropower plant has the utmost capacity to heal the existing low economic development, especially in rural areas. Micro hydropower plant can provide power for industrial, agricultural, domestic uses through direct mechanical power or by the coupling of the turbine to a generator to produce electricity (United Nations Industrial Development Organization (UNIDO) & International Center on Small Hydro Power (ICSHP), 2013). Hydropower in the context of developing countries like Ethiopia (with 8% of Africa’s hydro resource potential) has ten distinguishing characteristics: sustainability, dependence on local resources, cost effectiveness, durability, flexibility, simplicity, ability to fit into existing systems, accessibility to isolated rural communities, ability to meet multiple purposes and near immunity from inflation (Ramayya A.V., 2006).Electricity production by a hydro power has always been the major renewable electrical energy source. Besides, a comparison of the yield factors of renewable energy plant, suggests that hydropower remains the most valuable form of energy (Ramayya A.V., 2006).A study by the Ethiopian Electric power corporation (Ethiopian Electric Power Corporation (EEPCO), 2010) notes that Ethiopia has a huge potential for a hydro power development with an estimated capacity of 45,000 MW. However, the existing consumption stays merely less than 4.5 % of the existing potential. Moreover, access to electricity in Ethiopia is only about 35% with only 5,189 towns and villages out of 7,000 being electrified. Additionally, a study by the Embassy of Japan (Embassy of Japan in Ethiopia, 2008), suggests this figure does not represent the exact number of people with access to electricity, as the official number is calculated by the population living in the electrified area.

In a related study by the United Nations Industrial Development Organization (UNIDO) and International Center on Small Hydro Power (ICSHP), (United Nations Industrial Development Organization (UNIDO) & International Center on Small Hydro Power (ICSHP), 2013) Ethiopia, having a population of 91,195,675 (2010) and area of 1,104,300 km^2 with 89 percent of the gross population living in the rural setting, have a rural electrification estimated at a mere 2 percent. Although many studies infer that small and micro hydro power are not yet developed on a larger scale, three small hydro power station exist in locations called Yadot with a capacity of 0.35 MW, Dembi (0.8 MW) and Sor (5 MW) with a total of 6.15 MW. Additionally in February 2012, three Micro hydropower plants with a cumulative capacity of 125 kW were inaugurated. These power plants are located in the Southern Nations, Nationalities and Peoples'

Regional State (SNNPR) villages of Ererte, Gobecho and Hagara Sodicha in Sidama zone.

Other related studies made by the likes of Practical Action (Practical Action,…..) entails that a cross flow turbine stands as one of the best in medium and low head applications with relatively small discharge. In another study by Bilal Abdullah Nasir (Nasir B.A., 2013), the cross flow turbine is depicted as a hydraulic turbine gaining remarkable popularity in low head and small water flow rate establishments, additionally, due to its simple structure and ease of manufacturing it stands ideal for rural electrification as it incurs very small financial power.

6. ANALYSIS

6.1. Hydrological Cycle

The moisture from the surface of water bodies covering the earth's surface is transferred to the atmosphere as vapor and back to the water bodies again by precipitation. This precipitation could be in the form of rain, snow, dew, frost, hail or sleet (Gupta M, 2012). The major part of the precipitation occurs in the form of rain, while the minor part comes back in the form of snow. As a tropical region, the occurrence of fall of snow in the study area is almost none giving almost a hundred percent share for the rain (Web-4).

The catchment area denotes the total area that the rain fall measured in millimeters contributes to the stream at which the analysis is undertaken. The catchment area of the site under study is 12.64 Km^2, and the net head has been measured to be 30.5 meters considering a 6% loss inside the canal or penstock (Jicain collaboration with the department of Energy of Philippines, 2009). The discharge under each specific monthly mean rainfall has been calculated using the catchment area as an input (Ethiopian Meteorology Agency, 2014).

The flow duration curve clearly depicts the historical runoff data of the stream, from which one can choose the intended discharge depending on the power requirement and percentage of time the plant is needed to function in a given year.

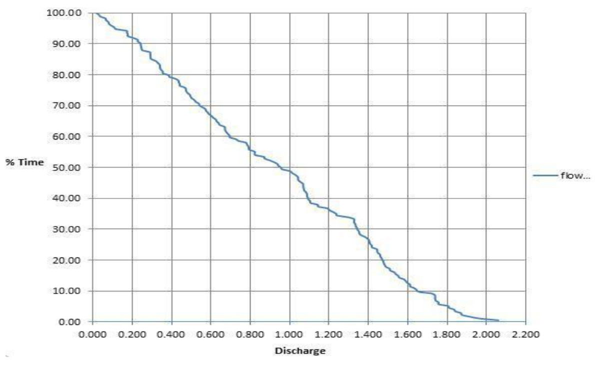

Figure 3 Flow duration curve

Depending on the power requirement of the site considering losses of distinct type and a reputable forecast on future needs, a discharge of 0.081 m^3/s is selected. This discharge has been seen to exist for 96.55 % of the year.

Figure 4 Shaft during manufacturing

Figure 5 casing disk during manufacturing

6.2. Turbine Component Design

The runner design followed existing empirical relations to come up with the basic figures and dimensions required for manufacturing. The Runner outer diameter is equal to 0.149m, with a blade thickness of 0.0026969m and a total of 18 blades wrapped about a disc of rim width equal to 0.0253m. The stress analysis undertaken using SOLIDWORKS has helped in coming up with the right material that could withstand the amount of force exerted from the flow through the nozzle.

Name	Type	Min	Max
Stress	VON: von Mises Stress	1.47732e-006 N/mm^2 (MPa) Node: 5506	1345.72 N/mm^2 (MP Node: 13156

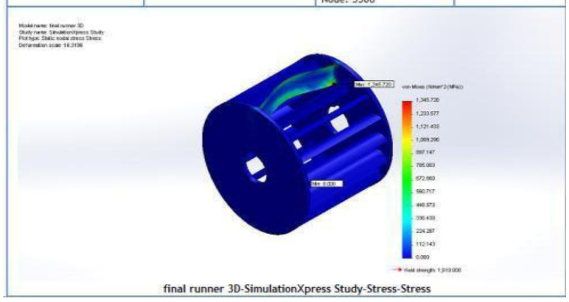

Figure 6 Simulated stress analysis of the runner

The nozzle of the cross flow turbine serves as a mouth through which the water enters into the belly of the machine. It assists the proper travel of the water from the penstock into the runner. The absolute velocity at which the stream of water enters the runner and hits the blades always makes a constant angle with the origin of the runner plates. To approximate this effect, a logarithmic spiral has been used. A logarithmic spiral is the only natural spiral in which each turn of curve makes the same equal angle with its origin (Viteazul B.M., 2005) (Schumacher O., Anstegard A.).And using a logarithmic spiral relation, the profile has been generated and the corresponding dimensions found.

Figure 7 casing spiral profile

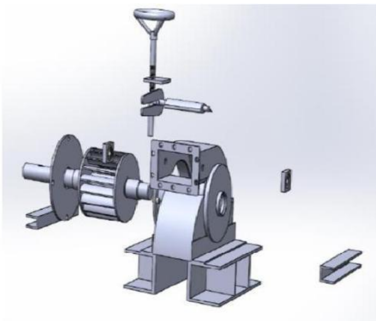

Figure 8 Exploded View of the turbine

The amount of power transmitted by a belt highly depends on the velocity of the belt, its condition of usage, its arc of contact with the pulleys and tension under which the belt is placed on the pulleys. And a v-belt has been selected considering the very remarkable advantages over other existing types. Power to be transmitted by the belt, rotational speed of the runner and the corresponding generator speed equally play a huge role in the analysis undertaken.

The shaft of the machine plays a massive role transferring the rotational speed of the runner to the generator via the belt. And its corresponding analysis has come up with the required dimensions for manufacturing. Moreover, its stress analysis has been thoroughly checked to find the optimal material.

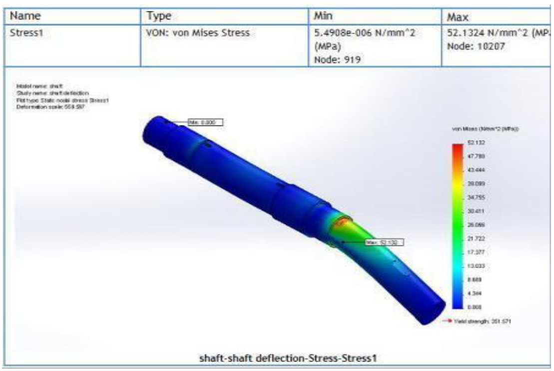

Figure 9 Simulated stress analysis of the shaft

On the other hand, one can use the software to design all the components of the turbine including the development of the flow duration curve. CFT Designer, abbreviated for cross flow turbine designer is the official name of the program. It initiates using the basic feeds of any micro hydro power plant designing procedure, Head and flow rate. Software is easy to use and has user friendly interface.

Figure 10 User Interface of designed program **Figure 11** Turbine after manufacture

7. CONCLUSION

Study, research and development in the area of renewable energy technologies is one of the leading tools in the advancement of a nation. The study has connected the industry to the academics in the development of this program as manufacture of the product has been financially aided by a private company. Although the capital cost in the construction of the civil work and installation of control units need more research to try and make both as cheap as possible, simplicity of manufacturing process of the different components of the cross flow turbine has been proved. Moreover, the usual failure of the machine when exposed to working environment due to poor and unanalyzed material selection has been scrapped off given the fact that all of the materials have been selected after a thorough analysis using simulation softwares studying their behavior when prone to different aggressive conditions. on top of all, development of the computer program that would assist the designing process has proved that one can finalize the process in a much shorter time armored with the most precise figure.

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