

Design and Analysis of Small Hydro Power for Rural Electrification Electrical and Electronics Engineering

Alie Wube Dametew¹

¹ Wollo University KioT

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Abstract

Hydropower, large and small, remains by far the most important of the ?renewable? for electrical power production worldwide. Small-scale hydro is in most cases ?run-of-river?, with no dam, and is one of the most cost-effective and environmentally benign energy technologies to be considered both for rural electrification in less developed countries and developed countries for further hydro developments countries (like Ethiopia). This paper addresses power generation for rural applications by means of small hydropower plants by using cross-flow turbine systems. The cross-flow turbine is suitable for installing small hydro-electric power plants in case of low head and flow rate. Using mathematical analysis a complete design of such turbines has been done in this paper.

Index terms— design and analysis, hydro power, renewable energy.

1 a) Introduction

The demand for energy is growing throughout the world. A combination of population growth, desire for improved living standards, and public policy has increased interest in green energy sources. Reliable access to electricity is a basic precondition for improving people's lives in rural and urban areas, for enhanced health care and education, and for growth within local economies ??By Ryan Cook, 2012). At present, more than 1.5 billion people worldwide do not have access to electricity in their homes (Kari Sørnes, 2010). An estimated 80% of these people live in rural areas; most have scant prospects of gaining access to electricity in the near future. According to International Energy Agency projections, by 2030, the number of people without electricity is not likely to drop due to population growth (www.ruralelec.org). Hence Electrical energy is an essential component in the developing process of any given location of the globe. Therefore, rural electrification remains an important issue in many countries. More often rural areas, which can also be seen as developing areas, are prone to several electrification problems and a common alternative to this has been for decade the use of diesel power supplies. However, diesel supplies are environmentally not friendly, less reliable and less efficient. A better alternative could be the use of renewable energy sources (such as, hydro-turbine, Biomass and wind turbine), in order to achieve optimum system design in terms of cost and efficient load demand satisfaction.

2 b) Back Ground of the Study

Hydro-power is considered as one of the most desirable source of electrical energy due to its environmental friendly nature and extensive potential available through out the world. Within the scope of hydro-electric power, small power plants have gained much attention in recent years. Small Hydro power Plants, being a mature technology may be optimally employed for sustainable power generation in rural communities in world wide. Hydropower plants convert potential energy of water at a height to mechanical energy which is used to turn a turbine at a lower level for generation of electricity (Anyaka Boniface Onyemaechi, 2013). In rural areas, small run-of-river hydro turbine is suitable for electrification because it is green, inexpensive, not fuel dependent, and is simpler to implement than other green energy technologies. A small hydropower scheme requires both water flow and

43 a drop in height called a head to produce useful power. Water in nature is considered a source of power when
44 it is able to perform useful work, particularly turn water wheels and generate electricity at a rate such that
45 the development of power can be accomplished in a most efficient and economical way(Adejumobi, I.A, (2011).
46 The research concerns to generate electric power From Small rivers and waterfalls could generate electricity to
47 energize many off-grid rural areas in Ethiopia.in addition to this the power gereateted by constructing small dam
48 or by the water water fill with two Continaeres and circulating them, and then to generet Power.

49 The relatively high electrification cost, especially for customers with low income The limitations of diesel
50 power.

51 However, substantial amount of Hydro -power is usually available in rural areas, and electric power generation
52 systems are often installed in these areas but still it is cost. Local electricity generation from hydro-turbine(Hydro
53 pwe) could overcome the above drawbacks and provide better economical alternative for the electrification system
54 in remote and rural areas. This paper shows the design, analysis and fabrication of small rural hydroturbine
55 electric power system.

56 3 d) Objective of the study

57 The main objective of the study is to design and Analysis of small scal hydro power.

58 i. Specific objective of the paper Select the proper materials for production of small rural electric power Design
59 , and analysis of \small hydro turbine rural electric power Contribute rural electrification system To develop a
60 sustainable, environmentally friendly alternative Renewable energy production (Contribute green environment
61 /environmental friendly). e) Scope of the paper ? Select proper material for small Hydro pwer ? Asses the
62 potentials and Impacts of Small Hydro power for development ? Design and analysis of small rural electric power
63 ? System Design of Samall hydro power

64 4 f) Research Methodology

65 In order to solve problems, engineers follow and apply different procedure and principles based on the problem
66 identifications. This project focus on the following activities Collecting relevant data related to hydro power
67 Design, analysis of hydro-turbine systems using mathematical and Numerical Methods(Matlab) Drive systems and
68 opraing principls Hydro-turbine system Design and Development Prepare Fabrication procedure each elements
69 of hydro turbine components Sammury and conclusion of the projectII. Literature Review a) General

70 Hydropower energy has the greatest potential of all the sources of renewable energy and if only a small amount
71 of this form of energy is used, it will be one of most important supplies of energy specially when other sources
72 in the country have depleted. hydroelectric power comes from water at work, water in motion. it can be seen as
73 a form of solar energy, as the sun powers the hydrologic cycle which gives the earth its water. In the hydrologic
74 cycle, atmospheric water reaches the earth's surface as precipitation ??Adejumobi, I.A,2011]. Some of this water
75 evaporates, but much of it either percolates into the soil or becomes surface runoff. Water from rain and melting
76 snow eventually reaches ponds, lakes, reservoirs, or oceans where evaporation is constantly occurring. Moisture
77 percolating into the soil may become ground water (subsurface water), some of which also enters water bodies
78 through springs or underground streams. Ground water may move upward through soil during dry periods and
79 may return to the atmosphere by evaporation. Water vapor passes into the atmosphere by evaporation then
80 circulates, condenses into clouds, and some returns to earth as precipitation. Thus, the water cycle is complete.
81 Nature ensures that water is a renewable resource.

82 5 Current hydro power status (World Wide)

83 Hydropower, large and small, remains by far the most important of the 'renewables' for electrical power production
84 worldwide. The World Hydropower Atlas 2000, published by the International Journal of Hydropower and Dams,
85 reported that the world's technically feasible hydro potential is estimated at 14,370 TWh/year, which equates to
86 100% of today's global electricity demand. The economically feasible proportion of this is currently considered to
87 be 8080 TWh/yr. The hydropower potential exploited in 1999 was 2650 TWh/yr, providing 19% of the planet's
88 electricity from an installed capacity of 674 W. 135 W of new hydro capacity is expected to be commissioned in
89 the period 2001-10. All other renewable combined provided less than 2% of global consumption. As illustrated
90 in Fig. ??,

91 6 Fig. 1: Exploited hydro potential by continent

92 North America and Europe have developed most of their economic potential, but huge resources remain in Asia,
93 Africa and South America. Small hydro (<10 MW) currently contributes over 40 GW of world capacity. The
94 global small hydro potential is believed to be in excess of 100 GW. China alone has developed more than 15 GW,
95 and plans to develop a further 10 GW in the current decade.

96 7 Small-scale hydro Hydropower (World wide)

97 Hydropower on a small-scale is one of the most cost-effective energy technologies to be considered for rural
98 electrification in less developed countries. It is also the main prospect for future hydro developments in

99 Europe, where the large-scale opportunities have either been exploited already, or would now be considered
100 environmentally unacceptable. Small hydro technology is extremely robust (systems can last for 50 years or
101 more with little maintenance) and is also one of the most environmentally benign energy technologies available
102 [Anyaka Boniface,2013]. The development of hydroelectricity in the 20th century was usually associated with
103 the building of large dams. Hundreds of massive barriers of concrete, rock and earth were placed across river
104 valleys world-wide to create huge artificial lakes. While they created a major, reliable power supply, plus irrigation
105 and flood control benefits, the dams necessarily flooded large areas of fertile land and displaced many thousands
106 of local inhabitants [Igbino, S.O,2007]. In many cases, rapid silting up of the dam has since reduced its
107 productivity and lifetime. There are also numerous environmental problems that can result from such major
108 interference with river flows. Small hydro is in most cases 'run-of-river'; in other words any dam or barrage
109 is quite small, usually just a weir, and generally little or no water is stored [Ryan Cook,2012]. The civil
110 works purely serve the function of regulating the level of the water at the intake to the hydro-plant. Therefore
111 run-of-river installations do not have the same kinds of adverse effect on the local environment as large hydro.
112 Hydropower has various degrees of 'smallness'. To date there is still no internationally agreed definition of 'small'
113 hydro; the upper limit varies between 2.5 and 25 MW. A maximum of 10 MW is the most widely accepted value
114 worldwide, although the definition in China stands officially at 25 MW. In the jargon of the industry, 'mini'
115 hydro typically refers to schemes below 2 MW, micro-hydro below 500 kW and pico-hydro below 10 kW. These
116 are arbitrary divisions and many of the principles involved apply to both smaller and larger schemes (Oliver
117 [aish,2002]). Mean annual rainfall ranges from 2,000 mm over some pocket areas in the southwest highlands,
118 and less than 250 mm in the lowlands. In general, annual precipitation ranges from 800 to 2,200 mm in the
119 highlands (altitude >1,500 m) and varies from less than 200-800 mm in the lowlands (altitude <1,500 m).
120 2 Parts of Ethiopia have uni-modal and others bimodal rainfall patterns.

121 8 Global

122 The Ethiopian government has for long recognized that economic progress will depend principally on the
123 development of the hydropower resources of the country. Ethiopia is endowed with abundant water resources
124 distributed in many parts of the country however, it has not made significant progress in the field of water
125 resources development during the past four decades. In particular, the exploitation of hydropower potentials was
126 not noticeably successful in spite of being given priority as a major field of national development. Considering
127 the substantial hydropower resources, Ethiopia has one of the lowest levels of per capita electrical consumption
128 in the world. Out of hydropower potential of about 15,000-30,000 MW, only about 360 MW (i.e. less than 2
129 percent) has been exploited by 1997 (Table 1).

130 9 Table 2 : Hydropower Plants and Installed Capacity

131 Presently, more than 90% of energy consumed in the country is derived from biomass fuels and is almost entirely
132 used for cooking. The use of these fuels has resulted in massive deforestation and soil erosion. The population
133 of Ethiopia was estimated in 1995 at 57 million and is thought to be growing at an annual rate of about
134 3.1%. In recent years, since the country has merged from the drought and civil war of the 1980's and since
135 the implementation of a comprehensive program of economic reform, the economy has recuperated and is now
136 growing. Such economic growth is essential to lift the people from severe poverty but can only be sustained
137 by adequate infrastructures and in particular adequate supplies of electrical energy. The expected continued
138 economic growth (in an environment of power shortage that had recently resulted in rationing) coupled with the
139 rapid expansion of the transmission grid, will increase the number of consumers and thus the total energy demand
140 in the next few years. This condition should evidently lead to an energy development program for accelerating
141 the development process notably in the undertaking of studies and preparation of detailed engineering designs
142 of hydropower projects that could be implemented within the shortest possible time. The major electric power
143 planning and market survey study conducted so far had forecasted power and energy demand and supply to the
144 year 2040. A 1993 forecast predicted the possibility of both power and energy shortages being very acute starting
145 from 1995. The existing power generation in Ethiopia and the projected energy requirements from the year 1990
146 through 2040 indicate and prove that the power generation needs to be increased by 4 times by the year 2000,
147 more than 14 times by 2020 and about 25 times [1994] [1995).

148 10 Ethiopian Projects Identified for Power Development The 149 Hydropower Potential of Ethiopia indicate

150 Ethiopia has a vast hydropower potential, which is estimated to be about 15,000 -30,000 MW. So far very little
151 percentage (less than 2%) of the vast potential has been harnessed. In order to develop this vast potential of power
152 several projects have been initiated to generate more and more hydroelectric power. Some 300 hydropower plant
153 sites in the whole eight river basins of the country with a total technical power potential of 159,300 Gwh/year
154 have been identified. Out of these potential sites, 102 are large scale (more than 60 MW) and the rest are small
155 (less than 40 MW) and medium scale (40-60 MW) hydropower plant sites (See Table 1).

11 2). Ethiopian Electricity sector overview After 2008

In 2009, 89 per cent of Ethiopia's population lived in rural areas and rural electrification was estimated at a mere 2-per cent (Gaul, 2010). The Government of Ethiopia launched its Rural Electrification Strategy in 2002 as a large governmental programme for electrification, consisting of three parts: grid extension by the public utility, Ethiopian Electric Power Corporation (EEPCo), private sector led off-grid electrification and promotion of new energy sources. The Rural Electrification Fund (REF) with its loan programmes for diesel-based and renewable energy based projects is the main implementing institution. With an initial budget of 29 million, REF has been supporting 180-200 rural micro-hydropower and photovoltaic (PV) mini-grids for educational and health care facilities (Hakizimana, 2009). The fund provides loans up to 95 per cent of investment needs with a zero interest rate for renewable energy projects. Renewable energy technologies that receive support under this programme include solar PV, mini-and micro-hydro, and biomass co-generation. According to EEPCo, the number of electrified towns and rural villages has increased significantly in the last five years of the strategic plan period. By July 2011 it had reached a total number of 5,866, bringing the country's electricity access to 46 per cent. In contrast, World Energy Outlook 2011 reported Ethiopia's 2009 national electrification access as 17 per cent (International Energy Agency (2011)). This difference is probably due to the different reference points and sources. The EEPCo has two electricity supply systems: the Inter -Connected System (ICS) and the Self Contained System (SCS). The main energy source of ICS is hydropower plants and for the SCS the main sources are mini hydropower schemes and diesel power generators allocated in various areas across the country are shown in the figure below. Typically, schemes of this size are considered to be more rapidly and easily brought to fruition as they require only modest investment and are likely to be appropriate for setting in rural areas to serve a number of communities. Any energy source that can be viably implemented in rural setting would contribute to the attractiveness of rural areas. Electric power would encourage the establishment of government offices and associated services in the more remote areas, improve the quality of educational, health and other services and enable individual rural households to have access to amenities which were formerly restricted to urban areas. The source of energy would also encourage the establishment of agro-processing and cottage industries, which would contribute to employment opportunities in rural areas. Nevertheless, since significant water resources are found in the rural areas, harnessing the power of falling water by means of small scale hydropower plants (less than 40 MW) as one way of providing affordable energy for the development of rural areas needs also to be looked into in detail along with the development of Medium Scale Hydropower Schemes and included in the top priority lists. Even if the the government has given priority to the development of Medium Scale Hydropowe potentials , but there is gap for the proper design, analysis and the way to generate and impment the system. theis research work is conducted to design and analysis of Small Scale Hydropower. The research concerns to generate electric power From Small rivers and waterfalls could generate electricity to energize many off-grid rural areas in Ethiopia. in addition to this the power gereateted by constructing small dam or by the water water fill with two Continaeres and circulating them, and then to generet Power. It is, therefore, in the next topic concerns the detail design and analysis of generating small hydro power for rular electrifications, so as to allow private individuals to be free in generating and selling electric power generated by small scale hydropower plants in rular cumminity in the country .

12 b) Components of Hydro System

A complete hydro power system consists of the following major components, which are discussed in this section.

Water storage and Water filtering mechanism Penstock with valves Turbine Power-converting device (Generator or direct-drive) i. Generating Power

In nature, energy cannot be created or destroyed, but its form can change. In generating electricity, no new energy is created. Actually one form of energy is converted to another form of diesel power to generate electricity, water must be in motion. This is kinetic (moving) energy, when flowing water turns blades in a turbine, the form is changed to mechanical (machine) energy. The turbine turns the generator rotor which then converts this mechanical energy into energy form electricity. Since water is the initial source of energy, we call this hydroelectric power or hydropower.

ii. Water Filtering A major aspect of system design that often is not considered is the removal of solid bodies from the water before it enters the turbine. If no such system is installed the turbine could suffer damage from sticks and stones, as well as reduced performance from leaves that get stuck on the blades. As this can never be totally removed the turbine will probably require cleaning at some stage for this design. There are several technologies available in order to stop these solid bodies from damaging the turbine or reducing its performance. A slanted box may be used in order to remove any surface material and then the outlet pipe may be situated higher than the bottom of the box so that any rocks are also removed, [BH Teuteberg March, 2010] iii. Penstock Following on the intake a length of pipeline is needed to direct the water to the turbine. Depending on the pressure in the pipeline it may be made of PVC or one of many other alternatives. The material should be appropriate to the application, which may in some cases be seawater. The pipe should also be strong enough to withstand the water pressure caused by the change in head.

215 **13 iv. Hydraulic Turbines Classification by Principle of Opera-** 216 **tion**

217 Hydraulic turbines extract energy from water which has a high head. There are basically two types, reaction
218 and impulse, the difference being in the manner of head conversion. In reaction turbines the water fills the
219 blade passages and the head change or pressure drop occurs within the impeller. They can be of radial, axial or
220 mixed flow types. In impulse turbines the high head is first converted through a nozzle into a high velocity jet
221 which strikes the blades at one position as they pass by. Reaction turbines are smaller because water fills all the
222 blades at one time in short a. Reaction Turbines Reaction turbines are low-head, high-flow devices. The flow is
223 opposite to that in a pump (from volute to eye of impeller after transferring most of the energy of the water to
224 the impeller) but a difference is the important role stationary guide vanes play. Purely radial and mixed flow
225 designs are called Francis turbines. At even lower heads an axial flow, propeller turbine is more compact. It can
226 be fixed bladed but better efficiency is obtained over an operating range by using adjust ble vanes, in the Kaplan
227 turbine.

228 **14 Design and analysis of Small Hydro Power for Rural Elec-** 229 **trification**

230 The diameter of the pipe should be chosen so as to minimize friction losses without inflating the cost.
231 [BH Teuteberg March, 2010]

232 **15 Hydro Turbine Electrical System**

233 Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity
234 generator, or other machinery to produce electrical power. The conversion process involves two main steps: -The
235 fluid dynamic power available in the water is first converted in to mechanical power -The available mechanical
236 power is then converted into electrical power. The power available is proportional to the product of pressure head
237 and volume flow rate. The general formula for any hydro system's power output is: where P is the mechanical
238 power produced at the turbine shaft (Watts), η is the hydraulic efficiency of the turbine, ρ is the density of water
239 (kg/m³), g is the acceleration due to gravity (m/s²), Q is the volume flow rate passing through the turbine
240 (m³/s), and H is the effective pressure head of water across the turbine (m). Water is taken from the river by
241 diverting it through an intake at a container. The container is a main barrier which maintains a continuous flow
242 through the intake. A turbine converts the energy from falling water into rotating shaft power.

243 **16 Hydro System Components Energy Consumption Estimate** 244 **of Rural Community**

245 Electricity consumption shows large variations depending on climate, culture, reliability of supply, and location.
246 Generally, rural households in developing countries such as Ethiopia have very low electricity consumption, with
247 the primary uses being for lighting and operation of radios, and televisions. In Ethiopia, official definition of a rural
248 community is one with a population less than 10,000 [3], with an assumed average household of 10. An average
249 energy demand estimate, E in kWh, of a given household within a rural setting may be computed using the
250 energy equation described by (Igbinovia, (2007). Where P_r is the wattage rating of a given household appliance
251 (component) in kilowatt (kW), t-is the duration for which the appliance is to be operated in hours (h), n is the
252 number of the appliance. The energy demand estimate has been expressed in kWh because it is fundamental unit
253 in which quantity of electricity (electric energy) used is measured. One kilowatt-hour is equivalent the amount of
254 work done by one kilowatt of electric power in one hour. Hence, in a rural household where lighting is the only
255 primary use of electricity, for instance, six 60-watt incandescent lamps used for about five hours each night will
256 have a daily consumption of 1.8 kWh based on equation (1). A radio set and a small fan of wattage ratings 20
257 W and 50 W respectively can be used for 10 hours each day for an additional consumption of 0.2 to 0.5 kWh. A
258 small TV set of wattage rating used for 6 hours a day will add a further 0.72 kWh. A family could accommodate
259 all these uses easily within a consumption range of 4 kWh daily. Adejumobi et al.

260 [Oliver Paish, 2002] in their work using Nigeria as a case study estimated the energy needed by typical
261 rural/remote environment ICT infrastructures, banking and hospital services. These results revealed that for
262 a typical rural/remote environment as it is applicable in Nigeria because the definition of a rural community
263 varies from communities to communities across different countries of the world, the total weekly hour energy
264 consumptions of ICT infrastructures, banking and hospital services could respectively be in the range of
265 48.836kWh, 72.908kWh and 12.660kWh equivalent to a daily average of 6.976 kWh, 10.415 kWh and 1.809
266 kWh respectively (Adejumobi I.A.).

267 **17 a) Water Diversion(Intake)**

268 The intake is typically the highest point of a hydro system, where water is diverted from the stream into the
269 pipeline that feeds the turbine. A water diversion system serves two purposes: provide a pool of water to create
270 an air-free inlet to the pipeline, and d remove dirt and debris [H 2, H5]. See Figure 8.1. Diversion System refers

271 to the means used to divert water from the source and transport it to your turbine. There are various methods
272 for diverting and transporting the water, but diversion systems can be grouped into two basic types: Open and
273 Closed systems. Matching the correct type of diversion system to a particular style of micro hydro turbine is
274 critical to the optimal performance of the turbine. In general, impulse turbines (which produce power primarily
275 from head pressure) will utilize a closed diversion system. Reaction turbines (which produce power primarily
276 from water volume) will normally work best with an open diversion system.

277 18 i. Closed Diversion Systems

278 In a closed diversion system (such as a pipe), the system is sealed and water is isolated from direct gravitational
279 forces while in the pipe. The water surface at the inlet to the pipe is the point at which gravity directly affects
280 the water, and is, therefore, the starting elevation for the system head. Closed diversion systems work well for
281 developing high pressure head with relatively low water flow volumes [H11].

282 19 ii. Pen Diversion Systems

283 In an open diversion system (such as a canal), the water along the entire diversion system is directly exposed to
284 gravity. In an open diversion system, then, the last point at which gravity directly impacts the water is the water
285 surface directly above the turbine inlet. Thus, the starting elevation for the pressure head is often the water
286 surface directly above the turbine. The ending point for pressure head is the turbine impeller. Open diversion
287 systems work well for supplying large volumes of water to the turbine with low friction losses [H11].

288 20 b) Pipeline (Penstock)

289 The pipeline, or penstock, not only moves the water to the turbine, but is also the enclosure that creates head
290 pressure as the vertical drop increases. The pipeline focuses all the water power at the bottom of the pipe, where
291 the turbine is. In contrast, an open stream dissipates the energy as the water travels downhill [H6]. One or more
292 bypass valves may be necessary. These should be installed at low points in the pipe to help get the flow going
293 and to flush out air bubbles. Figure 8.6 shows an example of the location of a pipeline relative to point of use.

294 21 c) The Head of hydro power

295 Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator.
296 In this case the energy extracted from the water depends on the volume and on the difference in height between
297 the source and the water's outflow. This height difference is called the head. The amount of potential energy in
298 water is proportional to the head [H1, H2]. To obtain very high head, water for a hydraulic turbine may be run
299 through a large pipe called a penstock, see Figure 8.1.

300 22 Design and analysis of Small Hydro Power for Rural Elec- 301 trification

302 Global Journal of Researches in Engineering () Volume XVI Issue VI Version I The height of head will also affect
303 the choice of turbine type selected. Based on the picture, the low head does not seem to use dam, even it uses
304 small dam (called barrage in the picture), meanwhile the medium and high head hydro power are using dam.,
305 the higher head means more installed capacity, which is defining the Where $V_1, V_2 =$ velocities at point 1 and
306 2 respectively (ft/s), $H_1 =$ Represents losses in pipe (ft). From Equation ??.2.3 we determine that the velocity
307 at the intake of the system point 1 is the same as the velocity in point 2, but not necessarily the same at the
308 turbine input. This is due to the use of nozzles at the pipe end in some cases $w_1 = w_2$ $yA_1 v_1 = yA_2 v_2$
309 (8.2).

310 23 5) added or withdrawn from the pipeline between stations 311 i. Net Head

312 Net head is the pressure at the bottom of the pipeline when water is actually flowing to the turbine. This will
313 always be less than the gross head measured, due to friction losses within the pipeline. Water flow figures are
314 needed to compute net head. Longer pipelines, smaller diameters, and higher flows create greater friction. A
315 properly designed pipeline will have a net head of 85 to 90 percent of the gross head measured.

316 24 Flow Measure

317 The second major step in evaluating a site's hydro potential is measuring the flow of the stream. Stream levels
318 change through the seasons, so it is important to measure flow at various times of the year. The use of the
319 stream by wildlife and plants must also be considered. Applicable permits should be sought from local agencies
320 overseeing natural resources and wildlife preservation. Never use all of the stream's water for your hydro system
321 [H3]. Flow is typically expressed as volume per second or minute. Common examples are gallons or liters per
322 second (or minute), and cubic feet or cubic meters per second (or minute). Three popular methods are used for

323 measuring flow: container, float, and weir. The container fill method is the most common method for determining
324 flow in micro hydro systems. Identify a spot in the stream where all the water can be caught in a bucket. If this
325 is not possible, a temporary dam can be built that forces all of the water to flow through a single outlet. the
326 specifications shall as a minimum cover/cost: s

327 ii. Design of Cross-Flow Turbine for Small Hydro-Power Hydro-power was considered as one of the most
328 desirable source of electrical energy due to its environmental friendly nature and extensive potential available
329 throughout the world. Within the scope of hydro-electric power, small power plants have gained much attention
330 in recent years. Several small hydropower schemes have been proposed and successfully implemented, which
331 include radial, axial, and propeller type turbines.

332 25 iii. Design steps for turbine a. Turbine Runner

333 The runner is the heart of the turbine. This is where water power is transformed into the rotational force that
334 drives the generator. Regardless of the runner type, its buckets or blades are responsible for capturing the most
335 possible energy from the water. The curvature of each surface, front and rear, determines how the water will
336 push its way around until it falls away. Also keep in mind that any given runner will perform most efficiently at a
337 specific Head and Flow. The runner should be closely matched to your site characteristics. Quality components
338 and careful machining make a big difference in turbine efficiency and reliability. Look for all-metal runners with
339 smooth, polished surfaces to eliminate water and air turbulence. One-piece, carefully machined runners typically
340 run more efficiently and reliably than those that are bolted together. Bronze manganese runners work well for
341 small systems with clean water and Heads up to about 500 feet. Hightensile stainless steel runners are excellent
342 for larger systems or abrasive water conditions. All runners should be carefully balanced to minimize vibration,
343 a problem that not only affects efficiency but can also cause damage over time.

344 b. The design procedure of the cross-flow turbine involves the following steps 1. Preparing the site data This
345 involves the calculations and measuring the net head of the hydro-power plant and its water flow rate.

346 ? Calculation of the net head (Hn)

347 26 $H_g = (H_{gross} - H_{losses})$ $H_g = H_{gross} - H_{losses}$

348 Where H_g = the gross head which was the vertical distance between water surface level at the intake and at the
349 turbine. This distance can be measured by modern electronic digital levels. For still water, this is the difference
350 in height between the inlet and outlet surfaces. Moving water has an additional component added to account
351 for the kinetic energy of the flow. The total head equals the pressure head plus velocity head, Q = flow rate
352 (m^3/s). 3. Calculation of turbine efficiency (η) The maximum turbine efficiency can be calculated as From
353 equation (4) above, its clear that the attack angle (α) should be kept as small as possible for maximum turbine
354 efficiency. The manufacturing of this type of turbine has shown that arc angle of (16°) can be obtained without
355 much inconvenience. 4. Calculation of the turbine speed (N): The correlation between specific speed (N_s) and
356 net head is given for the cross-flow turbine as :

357 Also the specific speed interms of turbine power in Kw, turbine speed in (r.p.m) and net head in (m) is given
358 as From equations (??) and (??) above, the turbine/runner speed can be calculated as: 5. Calculation of
359 runner outer diameter (Do) At maximum efficiency, the tangential velocity of the runner outer periphery is given
360 as From equations (??) and (??) the runner outer diameter can be calculated as: The drive system couples
361 the turbine to the generator. At one end, it allows the turbine to spin at the velocity that delivers the best
362 efficiency. At the other end, it drives the generator at the velocity that produces correct voltage and frequency
363 (frequency applies to alternating current systems only). The most efficient and reliable drive system is a direct,
364 1 to 1 coupling between the turbine and generator. This is possible for many sites, but not for all head and flow
365 combinations. In many situations, especially with AC systems, it is necessary to adjust the transfer ratio so that
366 both turbine and generator run at their optimum (but different) speeds. These types of drive systems can use
367 gears, chains, or belts, each of which introduces additional efficiency losses into the system. Belt systems tend
368 to be more popular because of their lower cost [H2].

369 i. Generator Typically in hydro systems the torque from the output shaft of the turbine is converted into
370 electricity by use of a generator. This provides great flexibility for the use of the power as the electricity is easy
371 to transport and use for multiple devices at the same time. In converting the energy from the shaft into electricity
372 some energy is lost. As the power from the turbine may be used to drive a pump, there will again be losses when
373 the electricity is used in the pump motor. Generator performance is comparable to motor performance and thus
374 the range of typical total efficiencies for just the electrical sub-system would be between 50% and 92%. The
375 efficiency of the motor is also relative to the load as motors running at partial load will be less efficient. It is
376 thus crucial to choose the correct size for the motor and therefore also the generator.

377 27 ii. Direct Drive Pump

378 The losses experienced in the generation and use of electricity may be avoided by connecting the shafts of the
379 Turbine and the pump. This means that most of the power generated in the turbine will reach the pump, with
380 small losses experienced in possible clutches and gearboxes. However, a major negative aspect of this solution
381 is that the location of the turbine system becomes more constrained as it needs to be situated next to the

382 pump it would power. This solution should be more efficient than a generator when powering a single constant
383 load such as a pump which runs all the time. As soon as multiple or variable loads are to be powered by the
384 turbine system a generator may prove to be a simpler and more effective solution.[BH Teuteberg March, 2010]
385 Operation procedure of Small Hydro turbine The generator in the system is the mechanicalelectrical converter in
386 the water turbine and the gearbox and rotor blades need to be designed to supply the motor with an input that
387 will yield the desired output power. This being said, a suitable motor first needs to be selected and tested to
388 determine the input speed required to produce 1-5 kW before any other design goes ahead. Once this has been
389 determined a rotor system and gearbox can be designed to produce the required revolution speed and torque to
390 supply mechanical power to the motor. In selecting a motor consideration needs to be made as to what type
391 of current is being produced and where it will flow to, if it will be stored or if it will be directly applied in an
392 electrical device and water pump. After connecting the motor shaft with water pump, the pump lift out water
393 from lower container to deliver the upper water tanker and then the water is circulating. the motor shaft is used
394 as an input for water pump and at the same time it generating power. Case-1, Reservoir Tanker-Valve/pipe
395 PAT-Motor-Gear Box/Mechanism-Water pump and also possible Case-2, Reservoir Tanker-Valve/pipe PAT-Gear
396 Box/Mechanism-Motor-Water pump

397 28 IV. Results

398 In this study, the design and Analysis of smallhydro-electric power for rural electrification is done, the theoretical
399 electric power generating potential and capacities for container (run-of-river) the systems are developed. Following
400 the standard small hydropower guide and past works are included, the turbine and generator efficiencies are
401 selected and designed. This design and Analysis of small -hydro-electric power is done using mathematical and
402 Numerical (Matlab) methods is applied. After introducing the site measurements and calculations as input data
403 to the computer program, the weir dimensions, open channel dimensions, penstock dimensions, turbine type,
404 turbine size, turbine power, turbine speed, turbine efficiency, generator specifications and gear box ratio are
405 determined. Figures ??3,4) show the relation between turbine power and speed with gross head at different
406 values of water flow rate. Figures (5,6) show the variation of turbine power and speed with water flow rate
407 at different values of head. From these results, the turbine power and speed were directly proportional with
408 the gross head, but there were specific points for maximum power and maximum speed in case of water flow
409 variation. Figures ???,8) show the variation of head loss with the gross head and water flow rate. It can be
410 shown that the head loss was increased very high with increasing the water flow rate than that with increasing
411 the gross head. Hydropower, large and small, remains by far the most important of the "renewables" for electrical
412 power production worldwide. Small-scale hydro is in most cases "run-of-river", with no dam, and is one of the
413 most cost-effective and environmentally benign energy technologies to be considered both for rural electrification
414 in less developed countries and developed countries for further hydro developments. The cross-flow turbine is
415 suitable for installing small hydro-electric power plants in case of low head and flow rate. A complete design
416 of such turbines has been presented in this paper. The complete design parameters such as, Trbine material,
417 runner diameter, runner length, water jet thickness, blade spacing, radius of blade curvature, turbine power,
418 turbine speed, number of blades, and any losses in the pipe due to friction, were determined at maximum turbine
419 efficiency.

420 i. Small-hydro power continues to grow around the world, it is important to show the public how feasible
421 small-hydro systems actually are in a suitable site. The only requirements for small-hydro power are water
422 sources, turbines, generators, proper design and installation, which not only helps each individual person but
423 also helps the world and environment as a whole. ii. Run-of-river or containwer small-hydro turbine schemes
424 generate electricity when the water is available and provided by the continer . When the container dries-up and
425 the flow falls below predetermined amount or the minimum technical flow for the turbine, generation will ceases.
426 iii. Medium and high head schemes use Weirs to divert water to the intake, it is then conveyed to the turbines
427 via a pressure pipe or penstock. Penstocks are expensive and the design is usually uneconomic due to the high
428 penstock friction head loss. An alternative is toconvey the water by a low-slope canal, running a long side the
429 container or river to the pressure intake or forebay and then in a short penstock to the turbine. iv. The choice
430 of turbine will depend mainly on the pressure head available and the water flow rate. There are two basic modes
431 of operation for hydro power turbines: Impulse and reaction. Impulse turbines are driven by a jet of water and
432 they are suitable for high heads and low flow rates. Reaction turbines run filled with water and use both angular
433 and linear momentum of the flowing water to run the rotor and they are used for medium and low heads and
434 high flow rate. v. Regulated turbines can move their inlet guide vanes or runner blades in order to increase or
435 reduce the amount of flow they draw. Cross-flow turbines are considered best for micro-hydro projects with a
436 head of (5) meters or less and water flow rate (1.0) m³/s or less. vi. Small-hydro power installations are usually
437 run-ofriver or container systems, which do not require a dam, and are installed on the water flow available on a
438 year round basis. An intake structure with trash rack channels water via a pipe (Penstock) or conduit down to a
439 turbine before the water released downstream. In a high head (greater than 50 m) and low water flow (less than



Figure 1: Figure 2]



Figure 2: Figure 3 :



Figure 3: Fig. 4 :



Figure 4: Fig. 5 :



Figure 5: Fig. 6 :



Figure 6: Figure 7 :



Figure 7: Figure 8 :



Figure 8: Figure 9 :



Figure 9:



Figure 10:



Figure 11: Htl 2 ?



Figure 12: 6 .



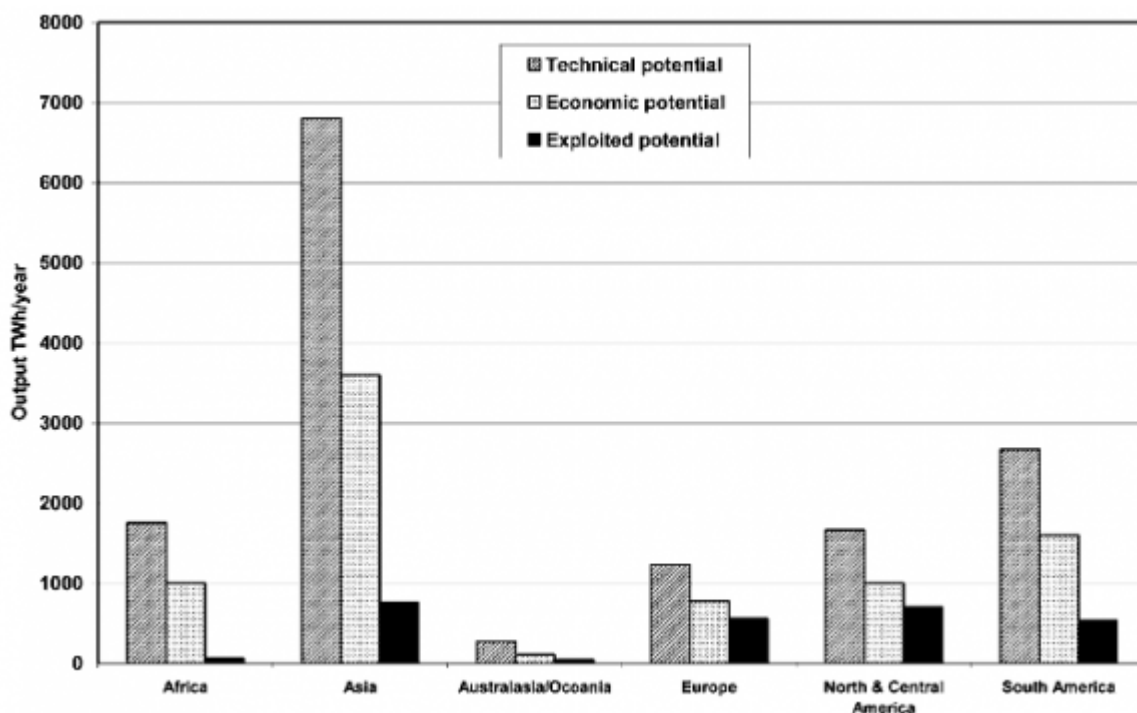
Figure 13: Figure 11 :



Figure 14: Figure 12 :

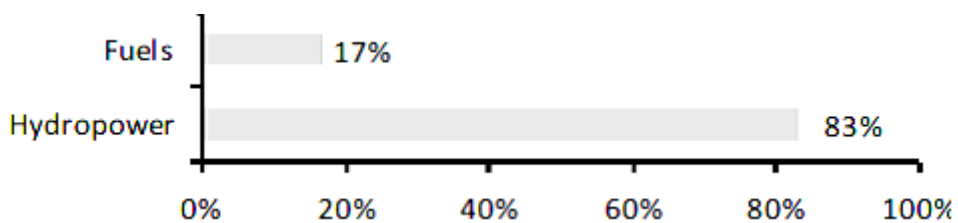
13 

Figure 15: Figure 13 :



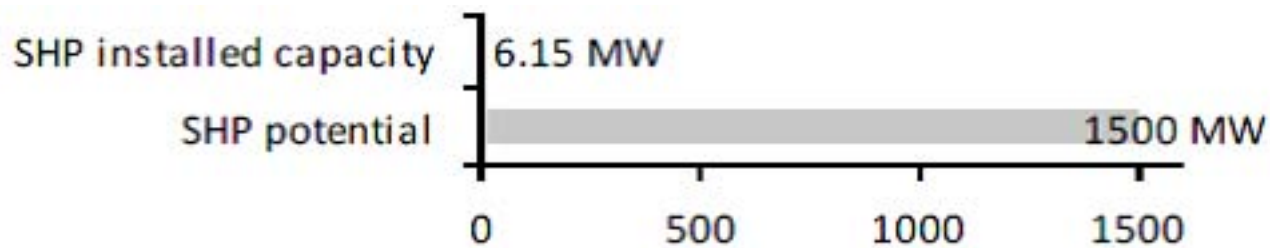
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Figure 16: Figure 14 :



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Figure 17: Figure 15 :



16

Figure 18: Figure 16 :



Figure 19:

Figure 20: Table 1 :

Design and analysis of Small Hydro Power for Rural Electrification by 2040. To overcome the deficiency in electric power supply, in Ethiopia, special attention has, recently, been given by the government to Medium Scale Hydropower Development (MSHD) in the range of 40 MW to 60 MW capacities, (rather than Large Scale Hydropower Development Schemes).

Source: World Small Hydropower Deve

Year	Plant	Finchaa HPP	MelkaWakena HPP	System	Installed	Guaranteed	Energy	Year
2016	AwashII HPP	AwashLII HPP	Koka HPP	ICS	Ca-	Capacity	Gen-	of
28	TisAbbey I HPP	Dembi HPP	Yadot HPD	ICS	pac-	MW	era-	Com-
() Vol-	Sor HPP	Total	Grand	ICS	ity	148	tion	mis-
XVI	Total	Total	SCS	ICS	MW	26	in	sion
Issue				LCS	100	32	GWH/year	1973
VI				ICS	153	3.8	5	1988
Ver-				SCS	32	0.3,5	616	1966
sion				SCS	32	6.15	434	1974
I F				SCS	43.2	340.95	135	1960
Global				SCS	11.4		135	1964
Jour-					371.6		70	27
nal					0.35		1,417	1990
of Re-					5	0.8	1.2	48
searches					6.15		2.8	52
in					377.75		1,469	1991
Engi-								
neering								

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Figure 21:

3

Name of River Basin	Number of Potential Sites			Total	Technical (GWh/year) Hydropower Potential	Percentage Share of the Total %
	Small Scale 40 MW	Medium Scale 40-60 MW	Large Scale > 60 MW			
Abbay	74	11	44	129	78,800	48.9
Rift Valley Lakes	7	-	1	8	800	0.5
Awas	33	2	-	35	4,500	2.8
Omo -Gibe	4	-	16	20	35,000	22.7
Genale -Dawa	18	4	9	31	9,300	5.8
Wabi Shebelle	9	4	3	16	5,400	3.4
Baro Akabo	17	3	21	41	18,900	11.7
Tekeze -Angereb	11	1	8	20	6,000	4.2
Total	173	25	100	300	159,300	

Figure 22: Table 3 :

4

Figure 23: Table 4 :

5

Figure 24: Table 5 :

10

Generator	Direct Drive Pump
Advantages Produces electricity which can be used in various areas	Much higher total efficiency
Can be purchased as a commercial package with the turbine/PAT	Simpler design, requires fewer components
The reliability of the turbine/PAT will not affect the flow of water	Cheaper, if existing pumps can be driven

[Note: Disadvantages Energy is lost in the generator Pump has to run at same rotational speed as turbine/PAT or gearbox is required Requires a complex electrical regulating system with a dump load Operation of system is dependent on reliability of both turbine/PAT and the Pump. More expensive The PAT/turbine has to be situated next to the pump] Small Hydro turbine System Design Figure 10: Schematic of systeme F © 2016 Global Journals Inc. (US)]

Figure 25: Table 10 :

440 0.5 m³/s), the turbine is typically Pelton type connected directly to a generator with control valve to regulate
441 the flow of water and turbine speed. ^{1 2 3}

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²© 2016 Global Journals Inc. (US) Source: Ministry of Energy and Mines

³© 2016 Global Journals Inc. (US) General

442 Also substitute equation (??0) into (20) to obtain the jet thickness at maximum efficiency as: 11. Calculation
443 the distance between water jet and the center of runner shaft (y_1) [2]:

444 12. Calculation the distance between water jet and the inner periphery of runner (y_2) [2] 13. Calculation
445 inner diameter of the runner (D_i)

446 14. Calculation of the radius blade curvature (r_c)

447 15. Calculation of the blade inlet and exit angles (b_1 and b_2) [2]: The blade inlet angles can be calculated as
448 The blade exit angle $2 = 90^\circ$ for perfect radial flow, but it must be equal to (1) at maximum efficiency.

449 16. The difference in elevation between the turbine and the upper reservoir is called the "head". Any losses in
450 the pipe due to friction or viscosity are converted into an equivalent form and when subtracted from the head the
451 result represents the "net available head". The losses are normally expressed in terms of a head loss Coefficient

452 The first head loss that is considered is friction losses in the pipe. The friction factor is highly dependent on
453 the Reynolds number of the flow, , If the Reynolds number is below 2100 it can be assumed that laminar flow is
454 occurring, in which case the friction factor is simply:

455 , If the Reynolds number is above this value there is a transitional period where it is not certain whether fully
456 laminar or turbulent flow is occurring. In this case turbulent flow is assumed and the applicable equation is:

457 In this equation the pipe roughness factor (e) is required. In The following Table ??able 8

458 .1 : Values of pipe roughness for various materials

459 When the friction factor is know it is simple to calculate the friction head loss coefficient using equation There are
460 also certain losses that occur at the pipe entrance. The losses occur as a result of the contraction and subsequent
461 expansion of water stream lines flowing into the pipe section. Some commonly encountered pipe sections also
462 induce losses in the system.

463 .2 Table 9 : Head loss coefficient for various pipe segments

464 The total head loss can now easily be calculated by using the head loss coefficient for each entrance, pipe section
465 and pipe material.

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