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OPTIMAL INSTALLATION OF GRAVITATIONAL WATER VORTEX POWER PLANT FOR RURAL ELECTRIFICATION

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Abstract

Micro hydro power plant (MHP) has been regarded as a promising renewable energy technology for rural electrification of off grid community since its installation began seventy years ago in Nepal. MHP projects carried out in Nepal are characterized as medium and high head, both of which are mainly installed in hilly region, where it is difficult to construct civil components due to unfavourable topography. This study focusses on prospects of installation of relatively new hydropower system for Nepal which requires small amount of civil construction known as Gravitational Water Vortex Power Plant (GWVPP). This paper presents the analysis of twenty-seven GWVPP installed in Asia, Europe, Australia and South America on the basis of technical and economic data provided by the organizations who are involved in those installations. Subsequently, the best technical solution for the optimal installation of GWVPP is proposed. In addition, cost components of those installations are compared and thus, economic site implementation plan that is suitable for site implementation in off grid community of Nepal is proposed. Moreover, the cost components are compared with that of existing MHP system of Nepal, and it is found that the civil works account for most of the total investment cost. So, three kinds of sites, having irrigation canal, weir, and reservoir beforehand, are proposed for site implementation so that civil works' cost are reduced. Theoretical designs for the civil works of GWVPP integrated into these water infrastructures are presented and construction costs are estimated. For verification, a scalable system of 1.6kW designed in the previous studies and integrated in an existing irrigation canal is used. This paper concludes that GWVPP is suitable for rural electrification of low head sites in Nepal, and for the optimal site implementation the civil works cost should be greatly reduced.

Keywords: Cost, Low head turbine,Rural electrification, Site implementation, Micro hydro

Introduction

Rural electrification is the process of providing electrical power to rural and remote areas where there is no grid expansion. Although there is advancement in overall global electrification rate from 76% in 1990 to 85% in 2012, and huge efforts have been made by practitioners in the recent years, universal access to clean electricity is still far from achieved as 1.1 billion people remain without access to electricity[1], while an additional 1 billion people lack access to advanced energy services [2]. Approximately 87 % of the people around the world without electricity live in rural areas characterized by remoteness and sparse population density, where the extension of national grids is often technically difficult, costly and inefficient. In context of Nepal, about 22%

of people are deprived of electricity[3] and most of them live in rural area.
Micro hydro power is one of the most cost-effective way of rural electrification [4] due to which it has been regarded as a promising renewable energy technology for rural electrification of off grid community of Nepal. Installation of the Micro Hydro Power (MHP) began in Nepal around sixty years ago and around 23 MW of micro hydro schemes have been installed in the country and around 250,000 households in the rural area are electrified by the micro hydropower plants [5]. Since micro hydro has lot of positive socio economic impacts, it has been well accepted by Nepalese society in this period, the pace of installation has increased from few kW per years to around 5 MW per year in sixty years [6]. However, due to unfavorable topography, accompanied by high cost of civil works, the development of this kind of technology has been still very slow. The cost and the environmental impact of constructing dams, canals and other civil structures make traditional hydropower projects difficult to develop. Although most of the potential sites having water resource qualify for hydro power generation in the hilly region of Nepal, there are certain areas that cannot be electrified because of difficulty in extension of national grid supply and erection of diversion structures [7]. This problem should be addressed either with the optimization of the existing micro hydropower system or with the new type of hydropower system which is economically feasible and environmentally acceptable.

Many research has been conducted in Nepal about optimization of construction cost of micro hydro-power system and conclude that the cost of micro hydro installation varies on site conditions[8][9][10]. According to the finding of R.R Parajuli et. al.[10], cost of the micro hydro powers (MHPs) are site specific and varied within range of 1500 USD and 1700 USD per kW of installation capacity at that time. According to his research, the cost breakdown of the Nepalese micro hydro sector shows electrical components cost 40%, civil components cost 30%, mechanical components 23%, and transportation and others cost 7% in average for Nepalese MHP systems. However, recent research conducted done through the installation data of AEPC of 39 different MHP above suggested that the cost of MHP system varies from 2000 USD per kW to 5000 USD per kW with average of 2836 USD per kW[8]. These studies also shows that the civil construction is one of the major cost component for construction of MHP in Nepal due to which it is difficult for the development of MHP in Nepal. So, this problem should be addressed with the new type of hydropower system which is economically feasible and environmentally acceptable.

Although micro hydro is accepted technology for off grid rural electrification in Nepal, many fewer low head turbines have been used for rural electrification of low head sites. GWVPP is very new typ of low head turbine technology for Nepal, however, research on the GWVPP has started in the year 2012 in Tribhuvan University Nepal [11]. Austrian engineer Franz Zotlöterer has recently developed a method of initiating and extracting energy from water vortices for micro hydropower generation, known as the Gravitational Water Vortex Power Plant (GWVPP) [12].It has a canal, a basinstructure and a turbine in which water passing through the canal is tangentially fed into the round basin structure to form powerful water vortex. The kinetic energy of the water vortex is converted into electrical energy with the help of turbine runner which is placed at the center of water vortex. An exit hole is made at the bottom of the basin through which the water vortex discharges [13]. Unlike most low-head micro hydropower plants, this turbine does not work on the pressure differential across the turbine runner blades to create the torque on the output shaft. Instead of that, it operates through the dynamic force of the vortex. Also, fish and small debris can pass through an operating GWVPP without causing damage to the turbine or harm to the fish. The GWVPP has several further advantages, such as homogenous dissemination of contaminants in the water, increment in heat of evaporation so water can reduce the temperature itself at rising temperatures in summer, and improvement in concentration of dissolved oxygen due to creation of vortex [12]. So, for a developing country like Nepal, this technology has a great potential to overcome the increasing electricity demand.

Many researches regarding GWVPP have been done in Nepal and other parts of the world. The current research has solely focused on the optimization of the design of basin structure and turbine to increase hydraulic to mechanical power conversion efficiency. But to commercialize any hydropower system at any site, there exists many factors that governs the optimal site implementation plan. This paper presents the analysis of twenty-seven GWVPP installed in Asia, Europe, Australia and South America on the basis of technical and economic data provided by the organizations who are involved in those installations. Subsequently, the best technical solution for the optimal installation of GWVPP is proposed. In addition, cost components of those installations are compared and thus, economic site implementation plan is proposed. Before the start of the case study of site implementation in Nepal, this paper attempts to compare the cost of existing MHP system with the cost of GWVPP installations. For a reference for comparision, most recent installation of Kerela from Aquazoom AG is taken as the cost of differents construction works of Nepal and India are comparable. It is found that the civil works account for most of the total investment cost. So, three kinds of sites, having irrigation canal, weir, and reservoir beforehand, are proposed for site implementation so that civil works' cost are reduced. Theoretical designs for the civil works of GWVPP integrated into these water infrastructures are presented and construction costs are estimated. For verification, a scalable system of 1.6kW designed in the previous studies and integrated in an existing irrigation canal is used.

Methodology

This research emphasizes on the optimal installation of GWVPP. Optimal in this case is the maximum technical performance and the most economic site implementation plan. First of all, comprehensive overview of the GWVPP design and its performance on the site is acquired through study of publications and reports on this technology. All four recognized manufacturers/promoters till date are inquired in order to get site installation data. Beside these four manufacturers, five other organizations who have conducted pilot installation of GWVPP are contacted.

After getting technical and economic data of twenty-seven installations from Asia, Europe, South America and Australia, these data were analyzed by distributing plant sizes in four classes and calculating mean efficiency along with the standard deviation. Because these installations utilize very low head, power density is used for the comparison of the power output instead of their efficiencies. In addition, the data of economic survey is analyzed and the major cost components of these installation are determined. After determining the cost components, which can be minimized, various sites are proposed for the economic site implementation with optimum technical performance.

The cost of the site implementation of GWVPP in Nepal is first predicted on the basis of the detail feasibility study of 10 kW GWVPP system provided by Alternative Energy Promotion Center, Nepal and the data provided by Aquazoom AG on recently installed 10 kW GWVPP system at Kerala, India. This predicted data is then compared with the construction costs of existing MHP system in Nepal. Then, three sites are chosen for the case study of implementation of GWVPP in Nepal. The first one is the pilot project done in an irrigation canal at Gokarna, Central Nepal. Two theoretical sites with existing weir and reservoir are taken for integration of GWVPP. The construction costs are determined for all three sites. Based on the analysis of the difference in the construction costs, the most suitable site out of the three is proposed.

Review of Past Inventions and Innovations

The research on the economic site implementation of gravitational water vortex power plant would be difficult to proceed without discussion on the past inventions and innovations on this technology. So in this section this paper discusses various patented and patent pending designs of GWVPP. Moreover, discussions on various innovations i.e. various past research studies which was done to improve the design of basin and turbine of GWVPP were also studied. This review would be reference for the design for economic site implementation plan.

Patents on GWVPP

To begin with, let’s discuss the very first patent on this low head hydro power technology. Although Viktor Schauberger introduced the idea of vortex flow [14] and Brown (1968) [15] introduced an idea for power generation from a free surface water vortex, we regard Franz Zotlöterer as a pioneer of today’s vortex hydro power technology as he not only created an internationally recognized multifunctional technology but also commercialized it.

Franz Zotlöterer's hydro-electric power plant [16]as shown in the figure 2a, b, c was granted patent in the year 2004. He later developed this concept to improve circulation in the vortex by modifying the basin shape from a rectangular channel to a cylindrical chamber with a tangential inlet, and slanted baffle guide was introduced in the system [17] as is outlined in Fig 2d in 2008. Later, Zotlöterer developed and patented an improved runner as shown in fig 2e which consisted of a cylindrical runner with a plurality of blades uniformly distributed over the circumference to improve hydraulic to mechanical energy transfer efficiency [18] in 2011. The height of the runner is designed to be equal to head of the power plant to which it is to be installed.

After a decade of filling of first patent on vortex hydro power technology, Kouris developed another technology which reduces the civil works to develop vortex hydro power by focusing on modularity.He proposed an assembly for generating electricity from flowing water which consist of a chamber having a base, a side wall extending from the base, a water inlet, and a water outlet, a rotor unit having a shaft and a rotor mounted to the shaft located in and rotatable in the chamber in response to water flow through the chamber, and an electrical generator coupled to the rotor unit for generating electricity in response to rotation of the rotor [19].
Before this, Kouris filled a patent for a new hydraulic turbine assembly for deriving extra energy out of a conventional hydroelectric power generating system by incorporating a second turbine generator at the inlet from the reservoir [20]. This patented device consists of a vertical water inlet pipe being extended into the water reservoir of a dam to deliver water to the conventional hydroelectric generating system. Inlet free vortex is formed by the vertical water inlet pipe having a water inlet point being positioned in the water reservoir. An Outer housing tube having an inlet cone for collecting water from inlet free vortex formation and an outlet draft in fluid communication with the vertical water inlet pipe to allow water to pass through the outer housing tube to the vertical water inlet pipe. A rotor and turbine assembly having a rotor unit and at least one generator unit for creating electrical energy is disposed within the outer housing tube to permit rotation of the rotor unit within the outer housing unit by water passing through the outer housing tube. We cannot find much commercialize projects of this kind as it is to be noted that such an arrangement would tend to lower the efficiency of the downstream turbine through the decrease in the discharge coefficient in the flow and the possible introduction of multiphase flow conditions to the downstream turbine.

In the year 2013, another company namely Aquazoom AG filed a patent in turbine that is claimed efficient for power production through water vortex power plant [21]. The turbine has circumferentially spaced blades that are joined together through a rotating connection element. The blades are provided with a receiving element. The connecting element is connected with the receiving element of the turbine blades. The turbine blades are limited in an inward region along radial direction at a bottom surface so as to form an opening. This turbine is made conical in shape in order that the turbine blades would get maximum thrust from water vortex core which is also somewhat conical in shape.

Past Research on GWVPP

As this technology is very new for the researchers around the globe, it has been an eye catching and interesting topic for researchers working on micro hydro power all-round the globe. There has been numerous research works conducted in many parts of the world on GWVPP based on the optimization of the runner and basin structure. Most of them have done numerical simulation and experimental verification works. So, this section of the paper attempts to review those past works.

Past Researches on Basin Structure

Many experimental and numerical studies has been done so far in various part of the world to optimize the basin structure of GWVPP. To begin with, Mulligan et al [13][22] discuss the ratio between the basin diameter and outlet tube diameter, concluding that to maximize the power output in cylindrical basin, the ratio of outlet tube diameter to basin diameter lies within 14%-18%. They also concluded that the lower range and higher range of d/D correspond to low and high head sites, respectively. One another computational study performed by Sreerag S.R et al [23] defines the outlet tube diameter correspond to the basin diameter for conical basin design. In this study, the tangential and radial velocities at different planes in the flow field for different outlet diameter was analyzed. After the analysis and validation of result with previous studies, it is found that maximum tangential velocities are obtained when outlet diameter approaches 30 % of basin diameter in conical basin design.

Wanchat et al [24][25] indicates the important parameters which can determine the water free vortex kinetic energy and vortex configuration are height of water in the canal, the orifice diameter, the condition of inlet and basin configuration. They propose a cylindrical tank with the incoming flow guided by a plate as a suitable configuration to create the kinetic energy water vortex and an orifice at the bottom center as the optimum design. Beside this study, many studies has been conducted at Tribhuvan University, Nepal for determination of geometrical parameters for efficient design of basin structure. One of the study conducted there in 2014, concludes that the for a given head and flow the different geometrical parameters that governs the conical basin design of a GWVPP are the basin opening, the basin diameter, the notch length, the canal height and the cone angle [26]. Another research conducted at Tribhuvan University, Bajracharya and Chaulagai et al [11] created water vortex by flowing water through an open channel to a cylindrical structure having a bottom whole outlet. The research concluded that for a fixed discharge condition, the height of basin, diameter and bottom exit hole are fixed, i.e., the basin geometry depends on the discharge supplied. This study suggests that, in sufficient flow condition, vortex minimum diameter is at bottom level and is always smaller the exit hole.

By the time of 2012, cylindrical basin was taken for research propose but Marian GM et al [27]introduce the concept of conical basin design for vortex hydro power plant. After this the research conducted at Tribhuvan University, Nepal in the year 2013 and 2014 [28][29] followed the conical basin design and the experimental and numerical studies concludes that the vortex formation is aided by the use of conical basin structure, with the output power and efficiency improved compared to a cylindrical basin structure. After this major researcher like Sreerag S.R et al [23] Dhakal. R et al [30][31]uses conical basin design for their research studies.

Past Researches on Turbine

The three patents on the vortex hydro power plants system clearly shows that the runner designs vary from one to another patents. So, there has been many studies done so far on the runner design. In 2016 Rahman et al. [32] experimentally tested four different turbine having different blade profiles in three different basin having different hydraulic head configuration. After analyzing the efficiency of each turbines it is concluded that higher rotational speed of the turbine does not guarantee higher hydraulic efficiency. Moreover, it is also concluded that maximum efficiency is when runner speed is half the vortex velocity. Christine et al from Trinity College, Dublin [33] investigate the operating conditions of the GWVPP experimentally by varying the inlet flow rates, inlet water height, runner blade sizes and blade numbers, recording the turbine rotational speed, vortex height and output torque for each setting using prony brake dynamometer. The research conclude that the turbine efficiency increases with blade area and blade number for the blade configurations tested.

The study on the effect of turbine material on the power generation efficiency from the water vortex hydro power plant is initiated by Sritram et al by the performance testing of turbine made up of steel and aluminum. His study concluded that light weight of water turbine can increase the torque and power generation efficiency [34]. Another study on turbine material is conducted in Thailand by Wichian et al [35] in 2016. He conducted the numerical and experimental study on the effects of addition of turbine baffle plates in the efficiency. This research concluded that the baffle plates fitted in turbine makes it more efficient, however, up to certain size only.

Lately, many research was conducted in finding the most efficient blade profile. The experimental and numerical research conducted by Rabin et al [30] on three different profiles of runner i.e straight, twisted and curved concluded that curved profile runner (blade curved in horizontal plane) with certain degree angle between hub and blade is efficient for power production in water vortex power plant. On the other hand, the numerical and experimental research performed by Kueh et al [36] and Khan et al [37] on various profiles of turbine concluded that the curved blade with blade curved in vertical plane is most efficient for energy generation from water vortex power plant.

Study on Past Installations of GWVPP

Zotloterer

Two years after taking patent first patent, Zotloterer do the first pilot installation of 10 kW vortex hydro power plant located in the Obergrafendorf, Austria. It gives an electrical power of 8.3kW from the height of 1.5 m and flow of 0.9 cubic meter per second. The efficiency of the plant is 63 % and generates green energy for about 15 single family houses (up to 60.000kWh) each year[12]. The pilot installation consists of four large radii curved runner positioned concentrically in the center of rotation as shown in fig 3a. Six year later, Zotlöterer use his patented improved runner which consisted of a cylindrical runner with a numerous blades uniformly distributed over the circumference to improve efficiency. Moreover, runner's height is designed to be equal to head of the power plant to which it is to be installed as shown in fig 4b. Although Zotlöterer installed GWVPP in various location of Europe, he have given technical data of some major successful projects only. In the later section of this paper, an attempt have been made to do analysis of those technical data.

In the economic case study provided by Zotoleter of his very first commercial project in Obergrafendorf, Austria, which is in operation since 2006. As the cost estimate was done in 2006 which would not hold good for 2018, So, we have expressed the cost component in terms of percentage of total cost for comparision with other installations. This installation has 6 m rotation tank with 1.5 m head in which 1200 lps of water is fed to produce vortex from a 20 m long canal. The total investement of 10 kW GWVPP in 2006 was 60,000€ which would be payback in seven years depending upon the model of investemnt. As the costs of maintenance and operation amount was around 1000€ per annum, there would be incomes of 70,000€ in 7 years of operation with total expenses of 67,000€.

Kourispower

Eight years after taking first patent on a concept of a system in which energy generation from vortex with less civil construction is possible and six year before taking second patent, Australia's first KCT Pilot Plant was consequently constructed at Marysville, Victoria on the Steavensons River near Steavensons Falls and has been in operation since august 2008. This demonstration plant harnesses 110 litres/sec and a 2m cylindrical vortex tank, which is only 60cm deep to produce 12 kWh per day. After this first installation, the installation of the Marysville 5kW KCT Mark 2, was completed in 2013 whose turbine rotate at ~180 rpm; the generator used, is rated up to 5kW at that speed under load. Other Installation of KCT are given in the table below.

An economic case study of a proposed power plant many locations of India was provided by Mr. Marco Stake of Kouris Power KCT [38]. According to him, for 10 kW installation of KCT, it requires basin of diameter 2.9 m and height of 2m where 500 lps of water is to be fed to produce water vortex. The total mechanical/electrical: works will cost around Euro 36,000 which include all the mechanical (tank, impeller, supports) and electrical (Permanent Magnet Generator, inverter) component. Civil co and transportation cost vary according to site, however, the total cost will be less than EUR45,000 for the total project.

Aquazoom AG (Previously known as Verde Renewables)

A year before registration of patent i.e in 2013, Aquazoom AG (Previously known as Verde Renewables) installed its first fish friendly micro hydropower plant in Großharthau near Dresden, Germany. The output is between 3.0 to 5.0 kW, depending upon the flow of water, which is enough to supply 10 households in Germany with electricity. However, this company has previously installed three power plants in Germany, Switzerland and India with another name called Verde Renewables. In the three installation with another name they used a different kind of blade which they modified later and applied for patent.

In an economic case study is provided by Aquazoom AG for its 10 kW Vortex Energy Plant constructed at Kerela, India in 2018. This installation has 2 m diameter cylindrical basin with 1.5 m head difference in which 1000 lps of water is fed to form water vortex from 5 m long canal. Actully there is two parallel basin to produce 20 kW. According to Dr.RechardVogeli, CEO of Aquazoom AG, the total investment cost for 10 kW system is 47000 USD in which the percentage of total cost associate with civil works, mechanical works, electrical works and transportation and others are 20 %. 45 %, 30 % and 5% respectively.

Turbulent Hydro

Lately, Turbulent Hydro started commercializing vortex hydro power plant with some design modification. They put the turbine near the outlet of the cylindrical basin and also used sloped inlet which can aid the transition of flow from smaller inlet channel into the vortex chamber. Beside these, they have also modified the turbine material by the use of the fiver composite with impact-proof coating.

Other Installations

Beside these four companies having different patents of vortex power plant, there are many other who have done pilot installation of GWVPP which are many done for research purpose but are also used for rural electrification. In 2016, a NGO called Khadagya installed 3.5 kW vortex power plant in Junin, Peru (# Site 24)[40]. The power is produced by creating vortex through 1.02 cubic meter per second flow in cylindrical basin structure with head of 1.2 m. The turbine used was similar to the Zotloterer turbine patented in 2011 [18]. They use a 4 pole three-phase synchronous generator with a spur gearbox (ratio of 1:28) to bring increase in the speed to 1500 rpm for 380 V power generation. Later they have modified the overall setup and makes it to produce 10 kW. Below are some details regarding the cost breakdown in USD for a 10 kW system (5.5 m diameter rotation tank). The total length of the infrastructure was about 100 m in order to obtain the required head.

In the year 2015, Green School of Bali installed vortex power plant in Bali, Indonesia (# Site 25). Although it does not look commercial, it can generate 15 kW of energy through 1200 lps flow of water to create vortex and height difference of 1.2 m [41] .The efficiency claimed was the greatest among all the installation around the world so far i.e 85 %. But for the technical analysis we have not taken this as the plant with higher efficiency as it is not a commercial project. Like Khadagya, this installation also incorporated turbine patented by Zotloterer in 2011.

In year 2016, University Technologi Malaysia installed 3 kW capacity (# Site 26) vortex power plant with cylindrical basin structure in an off grid community in PosLemoi Cameron Highlands, Malaysia. This was done mainly for research propose where different diameter runner was tested. Beside this, an organization based in Switzerland called GWWK-GenossenschaftWasserwirbelKonzepte installed a 10 kW capacity plant by forming water vortex from the flow of 1000 lps of water in a cylindrical tank of (#Site 26) 1.5 m height in . It was claimed that the power plant has efficiency of 68 % with power density of 10 kW per cumec.

In the year 2017, a very first installation of GWVPP (#site 27) with conical basin structure is done in the irrigation canal in bagmati river of Kathmandu Nepal by Vortex Energy Solution Pvt, Ltd [42]. A pilot system has been designed to produce 1.6 kW. The turbine is able to use all the available head of 1.5 m and a flow rate of 0.2 m^3/s [43]. A basin diameter of 2000 mm was chosen with a canal width of 1000 mm, and the predicted maximum operating efficiency speed is 95 rpm. To maintain a constant rotational speed at the maximum output power point, and ensure an AC output of 50 Hz / 230 V, an electronic load controller (ELC) is used.

Technical and Economic Analysis of GWVPP Installations

Every consumers need hydropower system that is technically and economically fasible for application in their desired site conditions. Based on the technical and economic data collected form 27 different installations around the globe, this secion of paper attempts to analyze the technical and economic parameters of GWVPP to propose the most effective technical and economic site implementation plan. Most of the data are collected from the past published research works and publicatoins form installer, however, some of the technical and economic data is collected by inquiry of installers personally.

Plant efficiency is most important parameter to evaluate any MHP system, but for the ultra low head sites the power density is more important than its efficiency. As the available head is nearly equall to zero to those sites power density is preffered to descirebe performance of these kinds of MHP system. Power density is power produced per unit volume of water passing through the turbine [44]. It can seen form the 27 installations from capacity 180 watt to 20 kW that, most of the installation are below 5 kW capacity. Moreover, we can clearly see form the Table 1 that the installtion having higher installation capacity have higher power density. Unlike power density, efficiency of these 27 installations are independent on the size (installed capacity) of the power plant.

The most important parameter for any devloper of micro hydro power to choose the type of MHP system is its efficiency. Zotlöterer claims that the maximum attinable efficiency of the vortex hydro power plant is approximately 83 %.However, from this study we have found installation with maximum effciency of 68% only, which was was obtained in the largest capacity turbine producing 20 kW. Moreover, the average efficiency of these 27 installations is 57 % with standard deviation of ± 5%. Looking at this scenerio, it seems that this technology cannot compete with other technologywhose efficiency isquite higher than this. For a instance, screw turbine has plant efficiency range from 75% to 94% [45], kaplan turbine has operating efficiency range form 62 % to 92 % [46]. However, the position of GWVPP in the turbine application suggested by Timilsana et al [47] that GWVPP system has a higher efficiency compared with a traditional undershot or overshot waterwheel with an efficiency in the range of 35 to 40% [48].

The study of optimization of installlation of Gravitational Water Vortex Power Plant cannot be proceded unless we study about the various cost components of these power plants. By studying the 27 GWVPP installations in many parts of the world in the previous section of this paper, we can conclude that the major cost components that effect the overall cost of installation of GWVPP are cost associate with civil works, mechanical works, electrical works and transportation and others. So, in this sectoin, attempt has been made to collect the data of these four cost components of various installations around the world and analyze the cost components to determine the most suitable site implementation plan for optimal installation of GWVPP.

The cost break down generated from economic case study of Zotloterer's installation, the cost of civil works is heighest among all other associated cost which makes it the most expensive installation among all other installation with total project cost 66,000 Euro. In comparision to the recent installations from Aquazoom AG and Turbulent Hydro, the Zotloterer's installation consists of cylindrical basin two or three times bigger in size which makes the higher civil works cost. Later Aquazoom AG and Turbulent adapted a smaller size cylindrical basin for reducing the civil works which in turn reduce the total project cost and percentage of civil works cost in the total project cost. Moreover, they also choose sites having existing water infrastructure like weir structure, reservoir, irrigation canal etc. in which minimum civil consturction is needed to divert the water to flow toward basin. Unlike other Kourispower adapted a system having less civil works among all other installer. According to economic case study of his 10 kW installaltion, he spend only 12

% of the total cost of Euro 45,000 in civil works.

It can be inferred from the previous section of this paper that the design of civil components progreses to minimize the cost of civil works from early patent of Zotloterer's to the latest patent from Kauris. Moreover, we can find many research articles on the issues and proposed solutions of the design of civil components to reduce the civil works cost. For a instance, in 2015 Dhakal et al [29] proposed a conical basin structure to devlop a artificial vortex which relieves the previous issues. Conical basin increases the vortex strength and ultametly optimize the basin size which will decrease the civil works cost to construct basin. However, the demerits of the conical basin is that the geometry is quite complex to build. It is even more complex when concrete is required to built the baisn thus requiring costly and complex civil works requirements. But the conical basin would probably be suited to the design of Kouris system [19] or any other system where the power plant is small in size. Later Aquazoom AG uses conical runner [21] instead of conical basin to optimize the power production which ultametely optimize the basin size.

Site Implementation Case Study in Nepal

The GWVPP can be installed in various low head sites in Nepal having adequate flow. For this case study three different theoritical sites are proposed and construction cost are estimated along with the civil design.

Proposed Design Requirements of GWVPP for Site Implementation in Nepal:

Nepal is known as a country of Himalayas (mountains) having mountain range in the north which acts as a perennial source for many free-flowing riversestablishing the country as second richest in water resources in the world after Brazil [49]. In Nepal, annual discharge of 174 billion cubic meters are available along with about 6000 rivers with total length of around 45,000 km [50]. Nepal has about 83,000 MW of hydroelectric potential, but only 753MW have been developed so far[51]. About 63% of Nepalese households lack access to electricity and depend on oil-based or renewable energy alternatives[52].The majority of Nepal's rural populations have been meeting their energy needs (mainly for cooking and heating) by burning various forms of biomass (forest wood, crop residues and dried animal dung) in open hearths or in traditional stoves. So, to electrify these community GWVPP is one of the cost effective and environmentally friendly technology which can provide green energy in cheap price in minimum construction time. So, we focus on the designs which use the locally available materials for its construction.

Analyzing the four different site implementation design from the previous section of this paper, we can conclude that the cylindrical basin made op of concrete is most suitable for the rural electrification of Nepalese community, which can be constructed by utilizing the locally available stone, gravels, sand etc. The basin size should not be as Zotloterer fat basin but should be smaller as in the installations from Aquazoom AG and Turbulent Hydro. Among the turbines used in different installations, the most recently patented design of Aquazoom AG is proposed as it can be locally fabricated and is most efficient too. The turbines used in Turbulent Hydro's installation is made up of fiber composite material with impact proof coating which cannot be fabricated locally. Similarly, the design of whole system of Kourispower's installation is portable but cannot be fabricated with the use of local materials as the components are made up of steel. The site implementation with integration of Dhakal et al's[29] conical basin structure is also suggested for lower capacity (<10 kW) having basin size less than 2 m as he bigger size basin require concrete structure and the geometry is quite complex to build locally.

Estimation of Construction Cost

Although there has been many detail feasibility studies going on in Nepal for commercialization of GWVPP in Nepal, there is no any single operating site in Nepal. So, in this paper a reference plant of Kerelaindia is taken to estimate a construction cost in Nepal[39]. The reference plant of India is taken as the comparison from the table generated form the rate list of the district coordination committee, Kathmandu [53] and builders association of Kerela[54]shows that the material and labor cost in Nepal and India is comparable. Moreover, a reference of a detail feasibility study report submitted at Alternative Energy Promotion Center, Nepal for installation of GWVPP in Sisa River in Solukhambu District of Nepal to estimate the construction cost[55]. Analyzing both the reports, it can be inferred that the investment cost for 10 kW system is at around 47000 USD [39] with distribution cost at around 7000 USD[42] to make total investment cost of 54000 USD in which the percentage of total cost associate with civil works, mechanical works, electrical works and transportation and others are 17 %. 40 %, 38% and 5% respectively.

Cost comparision with other MHP in Nepal

The estimation of construction cost of 10 kW GWVPP, suggest that the installation cost of GWVPP per kW is around 4700 USD and installation cost with cost of transmission is around 5400 USD per kW, which is comparable to the existing MHP system. This figure is almost constant for every installations compared to the existing MHP system where the cost varies due to variation in civil construction works as suggested by Dhakal et al [43]. Due to not requirement of very long canal, forebay and heavy intake structure, the civil construction works in GWVPP system is one third of the civil construction works in traditional MHP system. However, the electrical works in GWVPP system is nearly one and half times than in existing MHP system as GWVPP system require low rpm generator due to very small rotational speed of turbine. Similarly, the mechanical components cost is also higher due to the requirement of heavy gearing system hiving high gear ratio. Moreover, as the turbine is subjected to high torque due to low rpm the overall mechanical system obviously be more robust than the existing MHP system with turbine having high rotational speed.

Site Implementation Case Studies:

Existing Weir Structure Case Study (Theoritical Installation):

This evaluation considers a site with a sharp crested weir, as shown in Fig. The slat weir is constructed from a number of planks set into slots in the channel, which means they can be easily lifted in and out of the water course to change the weir height. We assume that the weir has a head of 1.5 m and a minimum flow rate of 0.4 m^3/s.

The design shown in Fig uses no concrete. Instead, the turbine is supported from the weir by a steel structure, made up from mild steel of 20m total length, 50mm cross-section. As there is little civil works the installation time is estimated at 4-person days.

Existing Reservoir Site Case Study (Theoretical Installation):

An example reservoir site is illustrated in Fig. 7. It is assumed that the reservoir is able to provide a flow rate greater than 0.4 m^3/s and has a head of 1.5 m. A weir is located on one side of the reservoir, with a river continuing from the reservoir

A gate is installed next to the weir, with a 1m by 0.8 m metallic canal attached to basin of turbine. The basin structure is located next to the metallic canal. The water is fed back to river through outlet tube at bottom of basin structure. This design uses 0.7 m^3 of concrete, therefore 1.1 tons of stone, 0.6 tons of sand and 0.3 tons of cement is required. The powerhouse is identical to the irrigation canal design. The stone is assumed to be locally sourced. The labor time for this installation is assumed to be 20 person days.

Existing Irrigation Canal Case Study (Pilot Installation):

This study is conducted to verify the two theoretical case studies. It is a very first installation of GWVPP with conical basin structure done in the irrigation canal in bagmati river of Kathmandu Nepal by Vortex Energy Solution Pvt, Ltd [42]. A pilot system has been designed to produce 1.6 kW. The turbine is able to use all the available head of 1.5 m and a flow rate of 0.2 m^3/s [43]. For this design, a basin diameter of 2000 mm was chosen with a canal width of 1000 mm, and the predicted maximum operating efficiency speed is 95 rpm. To maintain a constant rotational speed at the maximum output power point, and ensure an AC output of 50 Hz / 230 V, an electronic load controller (ELC) is used.

A sluice gate is built into the intake of the turbine to control the flow of water in turbine. The basin structure and canal are bolted onto a concrete section of the irrigation canal, where an inlet is cut into the side of the channel. The outlet water is fed to a nearby river or irrigation canal at a lower level through outlet tube. A small sheet metal outer covering is given to the generator and gearbox to protect the equipment from environmental effects. To implement this design, minimal civil works need to be carried out, only the cutting of the irrigation canal wall to create the basin inlet.

The structure can then be bolted to the canal, assuming it is strong enough. The installation time is assumed to be 4-person days.

Result and Discussion

The costs of each of the designs proposed are assessed using the material prices shown in Table. These costs are shown in Table with the breakdown for each material at the different sites.

The costs in Table show that irrigation canal is much less in comparison to reservoir and weir due to reduction of labor cost and civil construction material to make earthen canal. The labor costs make up the largest proportion of the civil works construction costs in the irrigation canal and reservoir installations, as they require a lot of manual labor to build the structures. However, with the simple design of the weir, then this is reduced dramatically making it much more cost effective. Therefore, another way to reduce costs further is to make the installation process as simple and short as possible

If the low-head gravitational water vortex turbine unit did not use the existing infrastructure, such as the irrigation canal, and required a 50 m intake canal to be built this adds another $ 1540 not including labor costs, which is another 49 % on top of the original build costs. Comparing the cost with the average cost of sites the proposed implementations are over 41 % cheaper at $ 2730/kW compared with $4700/kW.

Conclusion

After the study of the many successful stories of implementation of GWVPP in many parts of the world in this paper, this can be said that this low head hydro power technology can be one of the suitable options for the off grid rural electrification in the region having ample water resources and low head condition or where there is difficulty in construction of civil structures due geographical terrain. Although this technology is in primitive stage of commercialization as the very first installation was done by Zotloterer not long ago (2006) in Austria, we can find many inventions and innovations on this topic for its optimization. The major reason behind the interest of researchers and entrepreneurs around the world on this technology is its ability to perform with higher efficiency at ultra-low head region where no other power plant can perform better. The investigation of 27 GWVPP installations having different site implementation designs in various parts of the world from the various organizations shows that it operates at high power density in the plant of capacity more than 10 kW. The cost break down of the site implementation shows that the civil components' cost is the major cost which increases the total project cost. To address this issue, innovators have been trying to reduce this cost by reducing the size of basin structure and optimizing the turbine to extract more mechanical power from hydraulic energy from the power plant. The gravitational water vortex power plant, which is recently introduced in Nepal, has a potential in power generation in the remote villages where it is difficult and economically not viable to provide the national power grid. The GWVPP can supply electricity as per the Nepalese consumption pattern which is 200 households per installed power plant. As the site implementation cost of GWVPP is comparable with the existing MHP system available in Nepal, it has capacity to replace them in the low head region where there is difficulty in civil construction due to geographical terrain. Although, the electro mechanical cost is quite higher than that of the existing MHP system, reduction in the civil construction cost makes the overall cost comparable to existing MHP system. Its simple design also allows it to be fabricated in local basic workshops, allowing the design to be replicated across the world. The use of existing infrastructure reduces the cost of installed project greatly. The sites having weir, reservoir and irrigation canal in Nepal are acceptable for integration of GWVPP, among which irrigation canal is the most economical.

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Bibliography

[1] I. B. f. R. a. D. W. B. a. t. I. E. Agency, “Progress toward sustainable energy 2015: Global Tracking framework report,” www.worldbank.org, Washington DC, 2015.

[2] I. E. Agency, “World Energy Outlook,” International Energy Agency , Paris, France , 2011.

[3] P. Action, “Poor People's Energy Outlook 2017,” Practical Action Publishing Ltd, UK, 2017.

[4] ESPAM, “Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies,” World Bank, New York , 2007.

[5] K. A. &. T. Bajracharya, “Current Status of Micro Hydro Technology in Nepal,” in *IOE Graduate Conference 2013* , Lalitpur, Nepal , 2013.

[6] A. E. P. Center, “AEPC,” [Online]. Available: www.aepc.gov.np . [Accessed 12 09 2018].

[7] AEPC, “Renewable Energy Data Book,” Alternative Energy Promotion Center, Lalitpur, Nepal , 2015.

[8] S. W. K. K. Rabin Dhakal, “Technical and Economic Prospects for Site

Implementation of Gravitational Water Vortex Power Plant," in *5th International Confernece on Renewable Energy Research and Applications* , Barmingham, UK , 2015.

[9] K. R. A. &. T. Bajracharya, "Current status of micro hydro technology in Nepal," in *IOE Graduate Conference* , Lalitpur , 2013.

[10] R. R. Parajuli, "A Study on Cost Reduction Possibilities in Civil Components of Micro Hydro Power Systems," Department of Mechanical Engineering, Puchowk Campus, IOE, MSc Thesis Report, Lalitpur, Nepal , 2004.

[11] B. T. a. C. RK, "Developing innovative low head water turbine for free-fowing streams suitable for microhydropower in fat (Terai) regions in Nepal," in *Center for Applied Research and Development (CARD), Institute of Engineering, Pulchowk Campus* , Lalitpur, Nepal , 2013.

[12] F. Zotloterer, "Zotloterer- Smart Energy System," [Online]. Available: http://www.zotloeterer.com/welcome/gravitation-water-vortex-power-plants/. [Accessed 19 11 2018].

[13] S. M. a. P. Hull, "Design and optimization of water vortex hydropower," in *Department of Civil Engineering and Construction*, Silgo, 2010.

[14] B. A, "Hidden Nature: the startling insights of Viktor Schauberger," Adventures Unlimited Press, Kempton, 2005.

[15] B. KD. United States of America Patent 3372905, 1968.

[16] F. Zotloterer, "HYDROELECTRIC POWER PLANT". Patent WO2004061295A2, 2004.

[17] F. Zotloterer, "HYDROELECTRIC POWER STATION". Patent WO2008141349, 2008.

[18] F. Zotloterer, "HYDROELCTRIC POWER PLANT". Patent WO2008141349.

[19] P. S. KOURIS, "An assembly for generating electricity". International Patent Patent WO2015017881 A1, 12 Feb 2015.

[20] K. PS, "Hydraulic turbine assembly". USA Patent US6114773, 2000.

[21] C. J. P. U. K. P. &. L. P. Patrick Bletry, "Turbine for e.g. hydro-electric power plant with horizontal water swirl, has circumferentially spaced turbine blades that are limited in inward region along radial direction at bottom surface so as to form opening". International Patent Patent Application No : DE201210100399, 18 July 2013.

[22] C. J. Mulligan S, "The hydraulic design and optimisation of a free water vortex for the purpose of power extraction," BE Project Reprot Institute of Technology , Sligo, 2010.

[23] R. C. K. &. J. B. S. Sreerag S.R, "EFFECT OF OUTLET DIAMETER ON THE PERFORMANCE OF GRAVITATIONAL VORTEX

TURBINE WITH CONICAL BASIN," *International Journal of Scientific & Engineering Research, Volume 7, Issue 4, April-2016*, vol. 7, no. 4, pp. 457-463, 2016.

[24] R. S. S. W. K. T. a. P. K. S. Wanchat, "A parametric study of gravitational water vortex power plant," *Advance Materials Research* , Vols. 805-806, pp. 811-817, 2013.

[25] W. a. R. Suntivarakom, "Preliminary design of a vortex pool for electrical generation," in *Department of Mechanical Engineering, Khon Kaen University*, Khon Kaen, 4 Feb 2015.

[26] T. A. D. R. F. D. B. T. P. H. Dhakal S, "Efect of dominant parameters for conical basin: gravitational water vortex power plant," in *In: Proceedings of IOE graduate conference 2014, Centre for Applied Research and Development, IOE Pulchowk*, Lalitpur, Nepal , 2014.

[27] S. T. F. I. N. D. O. C. B. C. Marian GM, "The concept and theoretical study of micro hydropower plant with gravitational vortex and turbine with rapidity steps," in *World energy system conference (WESC) Asociatia Generala A Inginerilor Din Romania*, Romania, 2012.

[28] S. D. S. N. P. P. a. A. B. T. T. R. Bajracharya, "Development and Testing of Runner and Conical Basin for Gravitational Water Vortex Power Plant," in *Center for Applied Research and Devlopment (CARD)* , Lalitpur, Nepal, 2014.

[29] T. A. D. R. F. D. B. T. P. H. Dhakal S, "Comparison of cylindrical and conical basins with optimum position of runner: Gravitational water vortex power plant,," *Renewable and Sustainable Energy Reviews*, vol. 48, pp. 662-669, 2015.

[30] B. T. W. S. K. K. S. S. Dhakal. R, "Computational and Experimental Investigation of Runner for Gravitational Water Vortex Power Plant," in *6th International Confernece on Renewable Energy Research and Applications*, San Diego, USA, 2017.

[31] S. S. H. N. S. A. &. T. B. Rabin Dhakal, "Inlet and Outlet Geometrical Condition for Optimal Installation of Gravitational Water Vortex Power Plant with Conical Basin Structure," *Recent Advances in Mechanical Infrastructure. Lecture Notes in Intelligent Transportation and Infrastructure*, pp. 163-174, 2020.

[32] H. T. T. R. S. L. Rahman MM, "the efects of water pressure and turbine blade lengths and numbers on the model free vortex power generation system," *International Journal of Current Trends in Engineering Research (IJCTER)*, vol. 2, no. 9, pp. 13-17, 2016.

[33] A. M. a. P. C. v. 4. n. 2. p. 1.-1. M. 2. C. Power, "A Parametric Experimental Investigation of the Operating Conditions of Gravitational Vortex Hydropower (GVHP)," *Journal of Clean Energy*

Technologies,, vol. 4, no. 2, pp. 112-119, 2016.

[34] W. T. a. R. S. P Sritram, “Effect of turbine materials on power generation efficiency from free water vortex hydro power plant,” in *4th Global Conference on Materials Science and Engineering (CMSE 2015)*, 2015.

[35] S. R. Wichian P, “The efects of turbine bafe plates on on the efciency of water free vortex turbines,” in *Energy Procedia* , Japan, 2016.

[36] B. S. R. D. O. Y. Kueh TC, “Numerical analysis of water vortex formation for the water vortex power plant,” *Internatioanl Journal of Innov Manag Technol* , vol. 5, no. 2, pp. 111-115, 2014.

[37] K. NH, “Blade optimization of gravitational water vortex turbine,” MS Thesis of Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakisthan , 2016.

[38] K. P. Ltd., “Kourispower,” Kourispower Pty. Ltd, [Online]. Available: https://www.kourispower.com/gallery/. [Accessed 4 December 2018].

[39] A. AG, “Aquazoom Worldwide Projects,” [Online]. Available: https://www.aquazoom.com/projects/. [Accessed 5 December 2018].

[40] Kadagaya, “Vortex Hydro Electric Plant,” [Online]. Available: http://www.kadagaya.org/index.php/en/34-footerarticles/102-vortex-hydroelectric-plant. [Accessed 10 December 2018].

[41] D. O. Luviano, “The-Vortex-Hydroelectric-power-plant,” [Online]. Available: https://www.behance.net/gallery/28760179/The-Vortex-Hydroelectric-power-plant. [Accessed 10 December 2018].

[42] V. E. Solution, “BAGMATI GOKARNA PILOT TESTING PROJECT OF VORTEX POWER PLANT (1.6 KW),” [Online]. Available: https://vortexenergysolution.com/projects/bagmati-gokarna-pilot-testing-project-of-vortex-power-plant-1-6-kw/. [Accessed 9 December 2018].

[43] K. W. S. A. T. A. A. D. L. Dhakal. R, “Technical and Economic Prospects for Site Implementation of Gravitational Water Vortex Power Plant in Nepal,” in *5th International Conference on Renewable Energy Research and Application* , Barmingham, UK , 2016.

[44] S. B. B. J. Williamson SJ, “ Low head pico hydro turbine selection using a multi-criteria analysis,” *Renewable Energy*, vol. 61, pp. 43-50, 2013.

[45] W. H. I. K. F. K. B. P. Alois Lashofer, “STATE OF TECHNOLOGY AND DESIGN GUIDELINES FOR THE ARCHIMEDES SCREW TURBINE,” 2016.

[46] K. L. D. L. Kyle Kuhl, “KAPLAN TURBINE,” 2014. [Online]. Available: https://www.engr.colostate.edu/~pierre/ce_old/classes/CIVE%20401/Team%20reports/8%20-

%20Kaplan%20Kuhl%20Lai%20Lainel.pdf. [Accessed 7 December 2018].

[47] S. M. &. T. B. Ashesh Babu Timilsina, “Water vortex hydropower technology: a state-of-the-art review,” *Clean Technologies and Environmental Policy*, 2018.

[48] S. F. P. C. &. R. R. EMANUELE QUARANTA, “EFFICIENCY OF TRADITIONAL WATER WHEELS,” in *Proceedings of the 36th IAHR World Congress*, The Hauge, the Netherlands, 2015.

[49] K. S. C. Joshi NN, “Challenges and perspectives. Nepal: Social Watch,” 2009.

[50] W. a. E. C. Secretariat, “Energy Sector Synopsis Report,” Government of Nepal , Kathmandu, Nepal, 2006.

[51] I. H. P. Association, “Nepal's Statistics,” [Online]. Available: https://www.hydropower.org/country-profiles/nepal. [Accessed 10 December 2018].

[52] S. A. S. H. Sudeshna BG, “Power and people : the benefits of Renewable Energy in Nepal,” World Bank , Kathmandu, Nepal , 2011.

[53] G. o. N. District Coordination Committee Office Kathmandu. [Online]. Available: http://ddcktm.gov.np/wp-content/uploads/Darrate_073-074.pdf. [Accessed 12 December 2018].

[54] B. A. o. India, “Rates for reference including materials,” [Online]. Available: http://www.baikerala.com/bai/rates-for-reference-including-materials.php. [Accessed 12 December 2018].

[55] V. E. S. P. Ltd, “Detail Feasbility Study Reprot of Sisa Khola Micro Hydro Power Project 10 kW,” Alternative Energy Promotion Center, Nepal , Lalitpur, Nepal , 2016.

[56] P. Group. [Online]. Available: http://www.panchakanya.com/article-rates. [Accessed 10 December 2018].

[57] “Turbulent Hydro,” [Online]. Available: https://www.turbulent.be/. [Accessed 12 10 2018].

List of figures and tables

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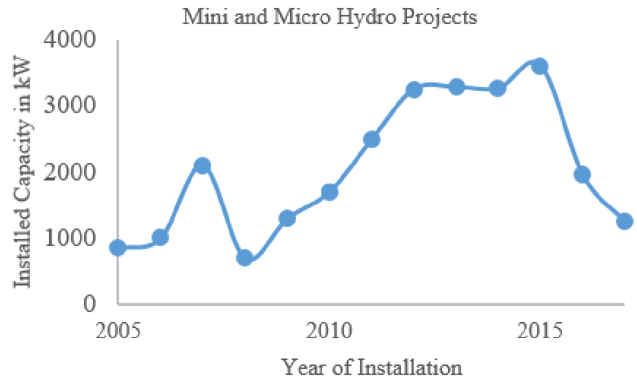

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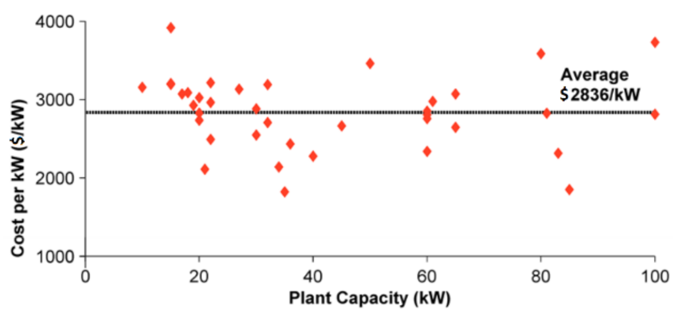

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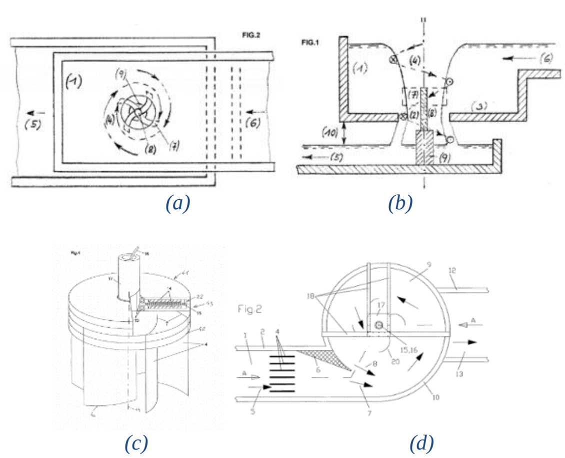

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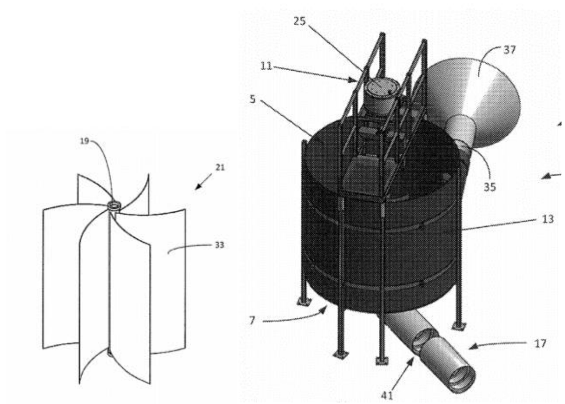
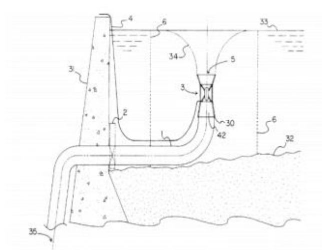


(a) (b)



(c)

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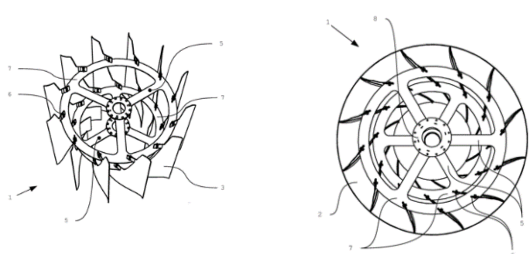

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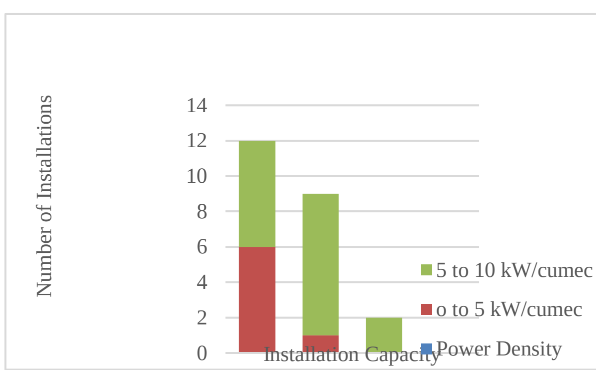

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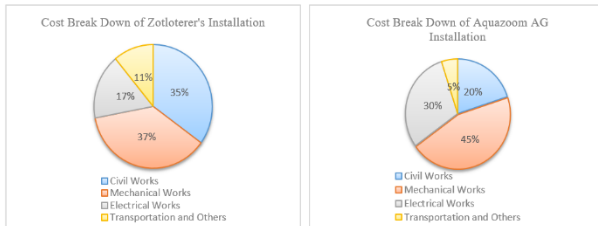

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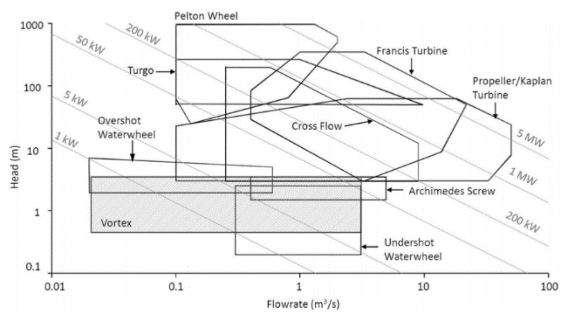

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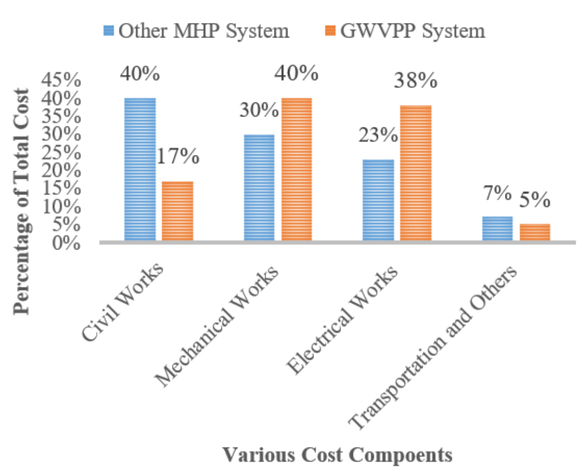

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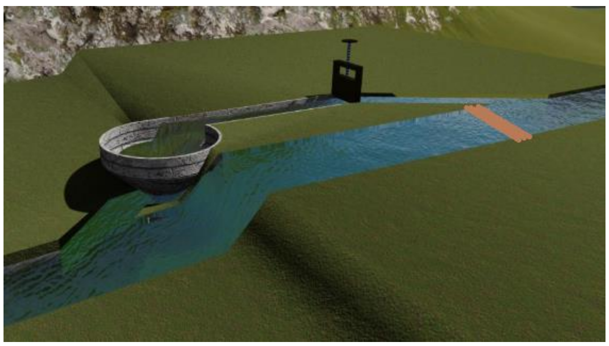

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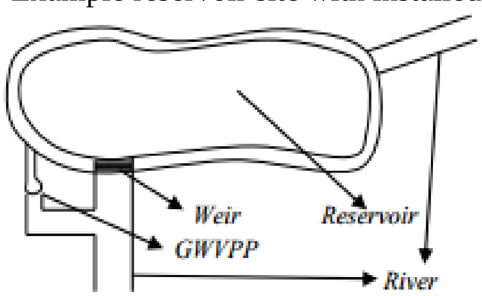

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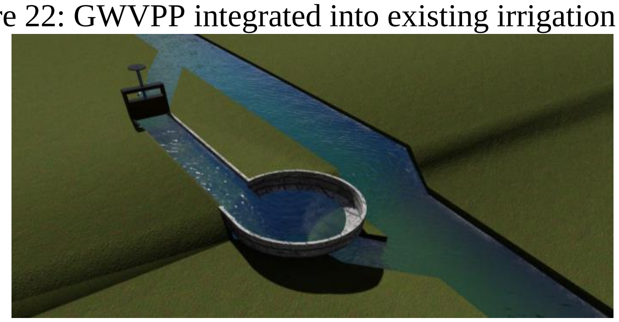

Table 1: Cost component table of Khadagya Installation

Cost Components	**Cost in USD**
Materials (e.g., cement, wood, steel)	7400
River side infrastructure (gabions, dyke, and gates)	2500
Consumables (e.g., hardware, tools, fuel)	7300
Electrical system (e.g., generator, cables, dump load, controllers)	3800
Transmission (gearbox, bearings)	5000
Turbine (axles, blades, bearings)	1200
Labor	17500
Total	**44700**

Table 2: Site Installation Technical data of 29 installation all around the globe

	Location	**Head**	**Flow**	**Power Output**	**Efficiency**	**Power Density**
Zotlöterer						
* Site 1	Austria	1.5	0.9	8.3	0.63	9.22
* Site 2		0.9	0.7	3.3	0.53	4.71
* Site 3		1.5	0.5	4.4	0.6	8.80
* Site 4		1.4	0.5	4	0.58	8.00
* Site 5		1.4	0.5	4	0.58	8.00
* Site 6		1.4	0.6	5	0.61	8.33
* Site 7		1.5	1	8.5	0.58	8.50
* Site 8		1.2	1.2	7.5	0.53	6.25
* Site 9		1.8	1	10	0.57	10.00
* Site 10		1.6	2	18	0.57	9.00
* Site 11		1	0.9	4.6	0.52	5.11
* Site 12		1.5	1	9	0.61	9.00
* Site 13		1.8	0.8	9	0.64	11.25
KCT						
* Site 14	Marysville, Australia	0.6	0.11	0.35	0.54	3.18
* Site 15	Braeside, Australia	0.8	0.05	0.18	0.49	3.6
* Site 16	Kalorama, Australia	1	0.1	0.5	0.51	5
Aquazoom AG						
* Site 17	Wesenitz, Sachsen	1.2	1.5	6	0.51	4.0
* Site 18	Suhre, Aargau	1.5	2.2	15	0.46	6.8
* Site 19	Dabka, Nainital	2	1.5	20	0.68	13.3
* Site 20	Germany	1.2	0.5	3	0.52	6.0
* Site 21	Kerela, India	1.5	1	10	0.68	10.0
Turbulent						
* Site 22	Belzium	2	0.25	3	0.61	12.0
* Site 23	Chilie	1.5	1.8	15	0.57	8.3
Khadagya						
* Site 24	Junin, Peru	1.2	1.02	3.5	0.29	3.43

Green School						
* Site 25	Indonesia	1.5	1.2	15	0.85	12.5
GWWK-GenossenschaftWasserwirbelKonzepte Schweiz						
* Site 26	Switzerland	1.5	1	10	0.68	10
Vortex Energy Solution						
* Site 27	Nepal	1.5	0.2	1.6	0.53	8

Table 3: Comparison of Material and Labour Cost in Kerela, India and Kathmandu, Nepal [53] [52].

Item	**Unit**	**Price in USD**	
		Price in Kerela (India)	**Price in Kathmandu (Nepal)**
Rubble	Per cubic ft	0.42	0.48
Red brick	Per bricks	0.09	0.11
Steel	Per kg	0.64	0.69
River Sand	Per cubic ft	1.54	0.70
Broken stone	Per cubic ft	0.45	0.49
Cement	Per 50 kg bag	11.67	7.33
Labour Masion	Per day	7 to 12	7 to 11
Labour Assistant	Per day	4 to 7	6 to 8

Table 4: Material and Labour Cost for Site Implementation [55][52]

Item	**Rate**
3mm Sheet Steel	$1.10/kg
Cement	$0.30/kg
Sand	$0.006/kg
Gravel/Aggregate	Locally sourced
Angle Steel (70x70mm)	$12/3m length
Ø50mm Steel	$1.00/kg
U-Channel	$1.20/m
Labor	$8/day

Table 5: Construction Cost of GWVPP in Example Sites

Item	Irrigation Canal	Reservoir	Weir
3mm Sheet Steel	950	950	950
Electrical System	850	850	850
Cement	85	100	85
Sand	50	120	50
Gravel/Aggregate	60	220	60
Angle Steel	85	70	95
Ø50mm Steel	60	60	60
U-Channel	140	140	140
Labor	450	650	650
TOTAL	$ 2730	$ 3160	$ 2940