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Potential of Generating Renewable Energy Using Picohydro Turbine from Wastewater

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***Abstract*— Fossil fuels depletion, climate change, global warming, and energy insecurity are driving factor, which has posed serious concerns over conventional energy sources. To mitigate and slow down these issues, the world is moving toward clean and renewable energy sources (RES). Amidst all RES, hydro is the most mature technology. Pico hydro installed over sewage pipelines and water supply pipelines, which is free from these concerns. Pico hydro turbines have great potential to electrify the rural and hilly areas. In this project, a Pico hydro turbine was designed which has installed on sewage pipelines to produce electricity. The project has three phases. In the first phase, sewage pipeline water quality has tested in a lab in terms of pH, dissolved solids, and suspended particles. As suspended particle and acidity of the water can result in failure and corrosion of turbine. The theoretical power and energy available in the sewage pipeline was calculated. If these two phases of testing enhance the feasibility of the project then the CAD model of the turbine has been made using solid works. Then lastly, the turbine has been manufactured and installed. This project use the flow of sewage water to produce electricity and help to reduce energy security, GHG emission, and global warming.**

Keywords*— Fossil fuels depletion, Climate change, Renewable energy sources (RES), Pico hydro turbine, Sewage pipeline, CAD mode, GHG emission

I. INTRODUCTION

Sustainable energy is being explored rapidly day by as fossil fuels are depleting and their cost is increasing due to energy insecurity as well as their negative environmental impacts [1]. Renewable energy has got great potential to meet the global energy demand and to overcome global warming and climate change issues. The state of the art known renewable energies are hydro, wind, solar, and hydrogen energy. Amidst all these renewable energy sources, the potential and efficiency of hydro energy cannot be underestimated for future power generation in terms of sustainability as well as environmental friendly behaviour [2]. As hydro energy is naturally available globally and produces no GHG emissions and other harmful emissions [3]. Of course, in terms of aquatic life, hydro energy poses a greater threat to aquatic life resulting in their killing and migration. But advancements in hydro energy technology in the form of gravitational water vortex system and other technologies have provided solutions regarding this issue [3]. Owing to be most ancient and matured energy technology among renewable energies, hydro energy is the most explored, secured, efficient, and reliable form of energy [4]. The statistical data of the world energy mix shows that hydro energy makes 20% of the global energy mix [7]. Using the natural tendency of water to flow from higher potential to lower potential, the potential energy of water is utilized to rotate the blades of turbines. The conversion efficiency of hydro from water to wire operation has been reported to be almost 90%. The capital cost of hydro schemes is relatively higher but they require very low maintenance which makes them more reliable and efficient [5]. Water flows from higher potential to lower potential thus, the potential energy gradually decreases and kinetic energy of water increases. This kinetic energy helps to rotate the blades of turbine and get converted into mechanical energy of the turbine. Now mechanical energy of turbine is converted into electrical energy by coupling the turbine with generator through excel. The working principle of hydro energy has been shown in Fig.1.The power produced depends upon the water head, storage capacity, and efficiency of the turbine and generator. Recent researches have been made on the exploration of simple hydro turbine designs to reduce the capital cost factor [5]. Hydropower is a vital source of energy for hilly and rural areas thus imposing less load on the central grid [6].There are different kinds of turbines, they are

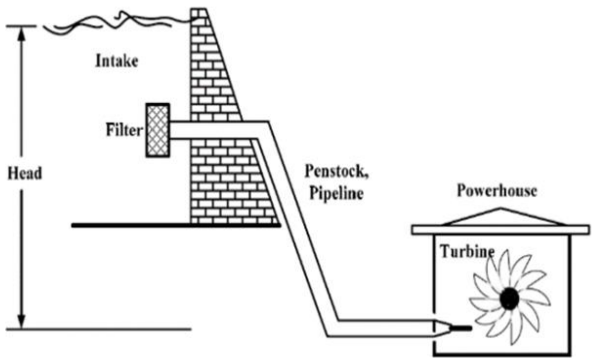

Fig. 1. Hydroelectric power generation

A. *Impulse turbines*

For low to high heads ranging between 6 feet to 600 feet, impulse turbines are preferred [7]. The kinetic energy of water in jet form rotates the runners of the impulse turbine to produce electricity. Water enters from the top side of the turbine and leaves at the bottom side with pressure equivalent to atmospheric pressure [7]. Impulse turbines are inexpensive due to their simple design. Impulse turbines are further categorized into following turbines which are suitable to be installed at low head [8]:Turgo, Pelton, and Cross-flow.

B. Turgo turbines

Fig.2. shown the design of a Turgo turbine which was made by Gilbert Glike back in 1920 [7]. These turbines find their application in medium to the high head range [6]. These turbines are efficient for higher flow rates and low head application as they outperform in power generation using more water and less head [9] [10]. Water jet strikes the runner and leaves it at bottom of the runner at a sharp angle thus presenting no interference to the inlet jet [4]. This feature of the turbine enables to have high rotational speed with a low diameter [9] [10]. This phenomenon has been explained in Fig.3.[9].

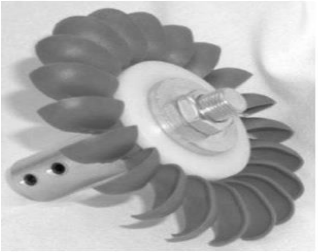

Fig.2. Turgo turbine

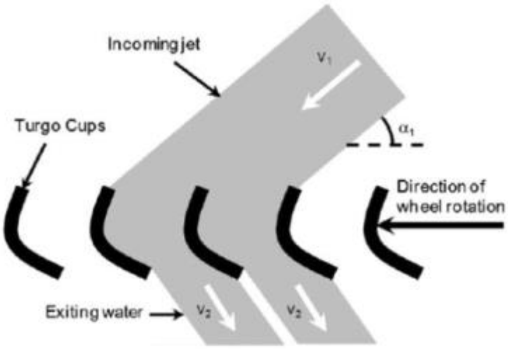

Fig.3. Turgo turbine working phenomenon

C. Pelton Turbines

Pelton turbine has been shown in Fig.4. in which it can be seen that how water strikes the cupped buckets of the turbine with the help of nozzles. These cupped buckets are arranged on the periphery of the turbine and help in turbine rotation. These turbines possess a higher efficiency rate ranging between 70 to 90 % [11]. The number of nozzles for the Pelton wheel turbine can be one or more than one depending upon the application. At sites having higher flow rate as well as higher head, similarly the sites having low flow rate as well as low head, impulse turbines are better choices in both cases [7]. For small-scale applications, single nozzle water jet is preferred [9] [10].

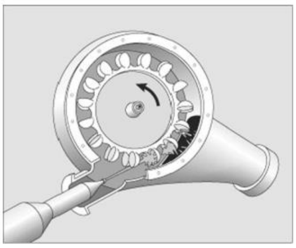

Fig.4. Pelton wheel for small hydro projects

D. Cross flow turbines

These turbines were designed by Ossberger Co, that why they are called Ossberger turbines. These turbines are drum-shaped having cylindrical-shaped runners. The cylindrical-shaped runner is equipped with curved vanes against which the rectangular section nozzles are directed. Crossflow turbines have the advantage that water flows twice through its blade. In the first cycle flow, flow is direct from outside to inside while in the second cycle, water flows from inside to back out. The design of cross-flow turbines has been shown in Fig.5.

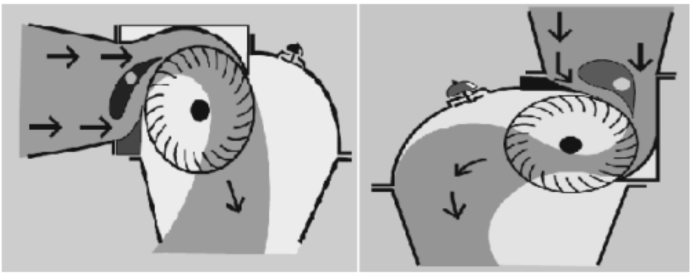

Fig.5. Inflow in horizontal and vertical orientations

E. Propeller Turbines

The reaction turbines which are in operation so far are mostly propeller type owing to their simple design, efficiency, and cost effectiveness [13]. Figure 1.6 shows the design of the propeller turbine having 6 blades on its runner. The striking rate of water on these blades is constant irrespective of their blade pitch which either is fixed or made adjustable [13]. Furthermore, turbine consists of three more major components which are termed as scroll case, draft tube and wicket gates. [14]. Further classification of propeller turbines goes into bulb turbine (unity cased generator installed on front of water flow), Straflo (generator directly attached to turbine circumference), Tube Turbine (penstock and generator connection is a straight line) [14] [15]. The Kaplan turbines are in fact the propeller turbines and have variable pitch. These turbines were first designed by Kaplan in 1913 thus has been named after its inventor. The only difference is that its hub is provided which a mechanism to adjust the blade's angle as well as the wicket gates. Figure 1.7 explains this phenomenon [12] [15].

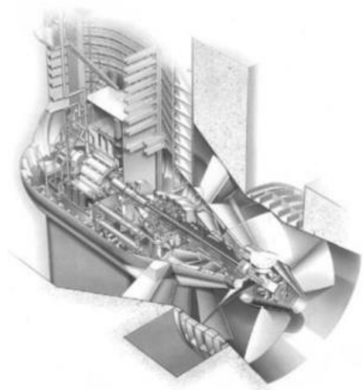

Fig.6. The bulb propeller turbine

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II. PROBLEM STATEMENT

Mostly the remote areas are deprived of electricity which is basic need of any society. This may be the case even in those countries which have extensive transmission and grid network. The demand of electrification in remote areas is of high concern. Despites of these concerns, most of areas are not electrified as power consumption rate in these areas is low and will put an enormous cost on transmission lines. Furthermore, the prices of other daily useable goods are also high in these areas. So, it demands for an on-site power generation technology which may full of their energy needs. Pico hydro turbines are best solution to this problem as they can be installed on water supply pipelines, sewage water pipelines or any nearby water fall and canals. The sole purpose of this project is to work on prototype of Pico hydro turbine which will enable the electrification of remote areas and isolated communities.

A prototype of Pico hydro will be made to study the current scenario of Pico hydro Electricity production for rural and hilly area, electricity production for on-site application and, the results obtained from this prototype will form a basis for large-scale application of Pico Hydro.

III. LITERATURE REVIEW

A. Pico hydro Overview

The Pico term in hydro technology stands for hydropower generating systems ranging between few watts to 5kW [20]. These systems are best suited for rural and hilly areas electrification with cost effectiveness [21]. The increasing inflation rates, as well as electricity bills, have urged people to find ways to maintain the standards of their lifestyles by producing electricity for their own. The sole purpose of Pico hydro is to serve the rural area's electrification needs. But these days this technology is made in use to generate electricity by regulating the water flow in domestic areas. The prototype of Pico turbines is designed to be installed at water supply pipelines and to produce electricity. These pipelines contain the huge potential to generate electricity but so far, this potential has not been explored and power generation from these Pico hydro systems is limited [22]. The potential of Pico hydro is not the same for all areas as the pressure of these water supply pipelines is different in the different areas thus potential will also be different. Also, the hydropower depends upon the water flow rate too so the potential will also depend upon the water flow rate in these water supply pipelines. Therefore, prior to the installation of the Pico hydro turbine, the head of water and water flow rate must be considered. These Pico hydro systems not only will reduce the load on the central grid but also help to reduce the threats posed by GHG emissions in form of climate change and global warming [20]. Also, the dependency on fossil fuels will be reduced resulting in a secure and reliable energy supply. As these hydro systems require no reservoir so the other advantages couples with Pico hydro are no deforestation, no threat to aquatic life, no soil erosion, and migration of local people [23]. Pico hydro are a type of run of the river in term of technology classification as they use the flow of water and put back into pipeline [24].

B. Background

Joel Titus et al. Designed a Pico turbine on sewage water pipeline. The impulse turbine design was such that it did not cause any loss in mass flow rate. The installation of turbine was done on the overhead tank outlet. The conversion of kinetic energy into electrical energy was done by using this turbine. The head of an overhead tank was 14m and discharge was 9 L/s. it was observed that at an average flow rate of 8L/s, the maximum power produced by this turbine was 212 watts. [25]. MJM Rizduan et al. work came out with the description of initial testing on Pico hydro prototype. This prototype was installed on domestic pipeline supplies which were using water kinetic energy to produce electricity without disrupting the water supply that is being used for cooking, laundry, and bath. The results of this prototype showed that some values of voltage were recorded from the generator which implies that Pico hydro is feasible for domestic electrification and can be further improved for large-scale application [26].Sujith Kumar et al. reported a study on Pico hydro economical models near green buildings. As Pico hydro is free of cost energy and cheaper than all other renewable energy sources. They reported that a Pico hydro can be integrated into any building and this system is capable of producing 100W to 500W which can illuminate 5 to 6 LED bulbs. [27]. OJAOMO et al. designed a Pico hydro prototype to harness the energy contained in falling water. The turbine used had a runner with a single jet and bucket geometry was hemispherical having 50mm diameter. The hydraulic head was 3.4 meters and the reservoir capacity was 2000 gallons. Results showed that this prototype was able to produce 45W of electricity with turbine revolutions of 500rev/min. They reported that the power generation could be enhanced if the system can be upgraded to a scale of 1:10 for the diameter of a runner, head, and capacity of the reservoir with a step-up transformer [28]. IW Ratana et al. developed a hybrid power plant (HPP) which consisted of solar PV and Pico hydro. HPP capacity was enhanced to 500-1000W in the second stage while it was 100-200W in the first stage. In the firsts stage, Pico hydro was producing 86W out of 100W while PV was producing 30W on a sunny day out of 100W. The output of Pico hydro was in AC which was converted to DC and combined with the Dc output of solar PV. This DC current was stored in 12V DC battery. The capacity of battery was 2-3A current which was enough to light a few LEDs [29].

IV. CONCEPTS & DESIGN

There are many impurities carried by sewage water that may include hair, human waste, bathroom and washroom waste as well. This requires the hydro turbine which may not be affected by the presence of these impurities. Because if these impurities cause blockage in turbine this will affect the overall performance of turbine. Therefore, the Pico turbines having hollow circle around its central axis will be used in this project so that impurities may pass through this hollow structure and may not cause the turbine blockage which will affect the turbine performance.Fig.7.shown below is design of hollow Pico hydro turbine which was installed at Toyogawa River-Basin Sewerage, Japan [4]. The area of pipe covered by the sewage flow was 10% so, the power produced was 328W. The efficiency sum of hydraulic efficiency, electrical and turbine was found to be 0.2P for this turbine. We will use same turbine design in our project with some adequate modification. A circular pipe is inserted between two stationary pipes, with their axes on a line. The inserted pipe is supported by two bearings; thus, the pipe can rotate around the central axis. A runner is embedded within the inserted (rotational) pipe. When water flows in the pipe, the runner and the pipe rotate integrally around the axis. A guide van is mounted at the end of the stationary pipe, just upstream of the rotational pipe.

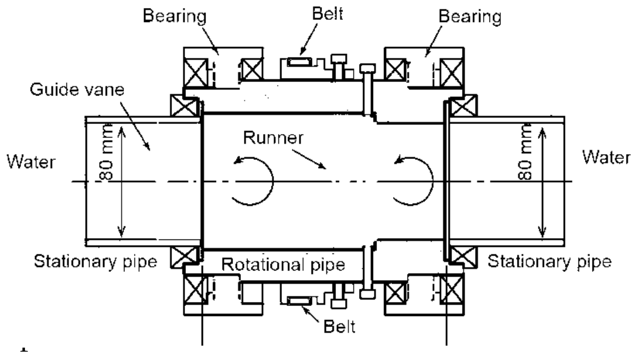

Fig.7. Design of Pico Hydro Project

Fig.8.shown below explains the runner. It has four blades, and a circular hollow is provided around the rotating (central) axis so that foreign matter included in the water can pass through the runner. The ratio of the hollow diameter D2 to the Pipe diameter D1. It is defined as the hollow ratio ε = D2/D1=0.375.

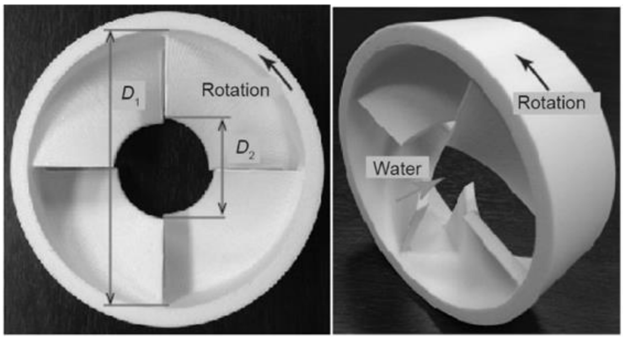

Fig.8.Runner Design

The runner is composed of a flat plate cascade. The Fig.9. shown below is 2D development view of blade. The width and thickness depends entirely upon the sewage pipe line diameter upon which turbine is going to be installed. This study will implement this design to perform experiment for power generation from Pico hydro turbine on sewage water pipeline. The specification of runner and turbine parameters can be changed to enhance the performance.

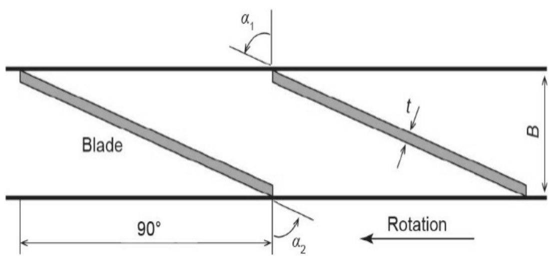

Fig.9. Development view of runner blade

The Fig.10. given below shows the hollow structure of guide vane provided around the central axis. This hollow structure will prevent the turbine to be blocked by impurities present in the sewage water. Thus, there will be no need to use water filters in this Pico hydro turbine.

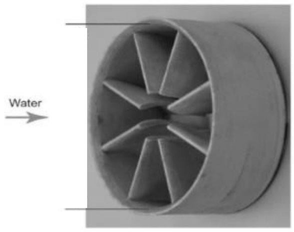

Fig.10. Guide Vane

The Fig.11. below shows the block daigram of the project implementation

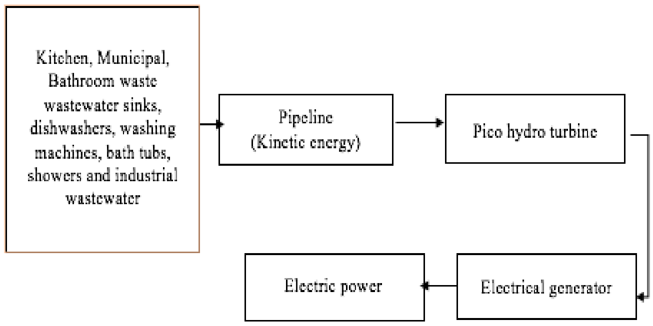

Fig.11. Block diagram

V. METHODOLOGY & IMPLEMNTATION

The overall project implementation and completion is divided into two phases.

A. *First Phase*

For the first phase, the inception and conceptual stage takes place. Within this phase, several researches will be reviewed which deemed appropriate for the project as well as identifying the problem statement for current objectives. Afterwards, measurement and data gathering will be starting at the control site and this may include the dimension of the water channel (m), flow rate (m3/s) and also velocity of water (m/s). From hand sketches to using Solid works CAD software, the overall design of the components for the system (Pico hydro turbine) are modelled in 3D.

B. *Second Phase*

This phase involves the implementation and analysis stage. The fabrication will involves connecting developed 3D printed pico-hydro turbine with an DC generator. After fabrication, site testing will proceed with the produced system model. Several measurements will be taken on site such as power output from the turbine (W), torque produced (rpm) as well as velocity of water flow and jet flow (m/s) which are important to study the effect of this parameters on turbine performance. Afterwards a feasibility study for implementing system for the generation of electricity from waste from industrial environment will be carried out.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 11 Issue 03, March-2022

The Fig.12. below shows the flow chart of the overall implementation. The project have been designed on the solid works software installed on the PC. The Indivual of the project will be discussed with specified dimensions as per the requirement.

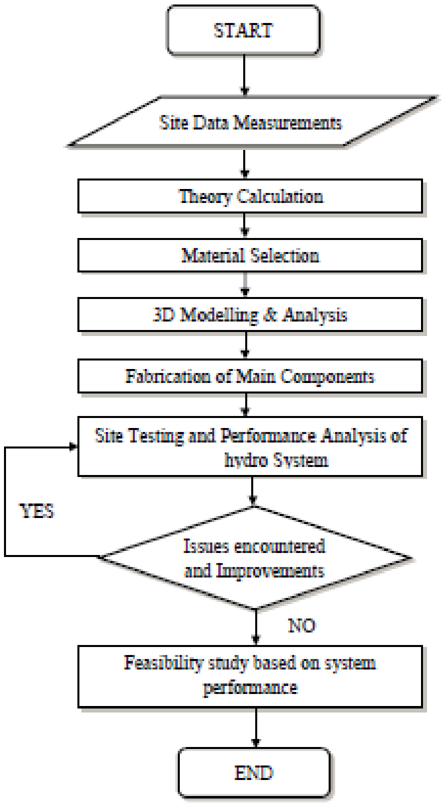

Fig.12. Methodology & Implementation flow chart

C. CAD Design

Fig.13. Runner blade

Runner blade this is the main component of the turbine that route the body in order to generate electricity.

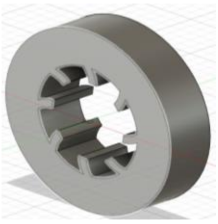

Fig.14. Water guides

Water guides this prat guide water to hit the blade of the runner directly.

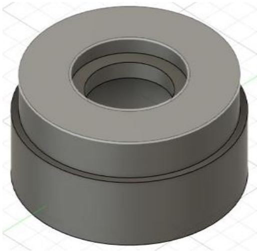

Fig.15. Bearing holder

This part holds the bearing in order to able the turbine to rotate the generator.

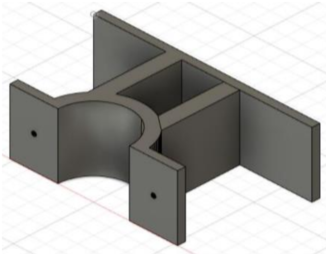

Fig.16. Generator holder

Generator holder this par holds the dc motor.

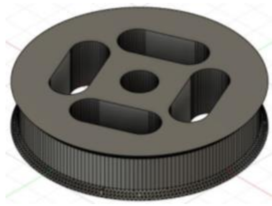

Fig.17. Timing belt

Timing belt poly this part attached to motor.

Fig.18. Turbine poly

Turbine poly this part attached to the turbine.

VI. SIMULATION RESULTS

The sewage water current in the pipeline hits the turbine with pressure as the magnitude of this pressure decreases or increases depending on the location of this turbine within the pipeline. The hollow turbine design makes it easier for the solid impurities present in the sewage water to pass through the turbines begin to rotate under the influence of the flowing stream of high pressure water. When the turbine is in motion, the motion is transmitted through the rubber belt to rotate the generator. When the generator is rotating, it produces electricity, which in turn feeds the local network with electricity, or it may be used to supply electricity to remote areas that cannot get it from the network.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 03, March-2022

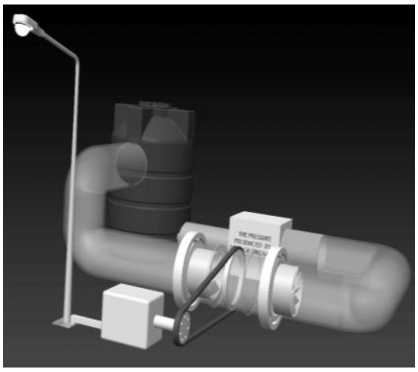

Fig.19. Simulation Result

VII. RESULTS AND ANALYSIS

We made our experiments to study the hollow Pico turbine electric outputs and to know how this designed system can deal with the different types of water:

Case 1: Testing using Tap Water.

Case 2: Testing using drainage water with less contamination.

Case 3: Testing using drainage water with medium contamination.

Case 4: Testing using drainage water with high contamination.

A. Case1: Testing using tap water.

Fig.20. Case 1 Result

TABLE 1. Case1 result: Testing using tap water.

	Units	Case1
Gravitational acceleration	m/s	9.8
Density of water	Kg/m^3	1000
Radius of Pipe	m	0.03
Cross sectional Area of Pipe	m	0.002826
Length of water	m	0.5
Width of water	m	0.32
Depth of water	m	0.15
Ar= w × d Cross-sectional area of the channel	m²	0.048
Vr Average stream flow velocity	m/s	0.7
Water Head	m	1.5
Vm=vr*1	m/s	0.7
Q = Vm× Ar	m^3/s	0.0336
The water flow rate	m^3/s	0.0336
Voltage produce	V	5.5
Current produce	A	0.02
Power produce	W	0.11
Efficiency =power/density* height* Gravitational acceleration*water flow	%	0.022271

B. Case 2: Testing using drainage water with less contamination.

Fig.20. Case 2 Result

TABLE II. Case 2 result: Testing using drainage water with less contamination

	Units	Case2
Gravitational acceleration	m/s	9.8
Density of water	Kg/m^3	1000.1
Radius of Pipe	m	0.03
Cross sectional Area of Pipe	m	0.002826
Length of water	m	0.5
Width of water	m	0.32
Depth of water	m	0.15
Ar= w × d Cross-sectional area of the channel	m²	0.048
Vr Average stream flow velocity	m/s	0.5
Water Head	m	1.5
Vm=vr*1	m/s	0.5
Q = Vm× Ar	m^3/s	0.024
The water flow rate	m^3/s	0.024
Voltage produce	V	3.6
Current produce	A	0.01
Power produce	W	0.036
Efficiency =power/density* height* Gravitational acceleration*water flow	%	0.010204

C. Case 3: Testing using drainage water with medium contamination.

Fig.21. Case 3 Result

TABLE III. Case 3 result: Testing using drainage water with medium contamination.

	Units	Case 3
Gravitational acceleration	m/s	9.8
Density of water	Kg/m^3	1000.3
Radius of Pipe	m	0.03
Cross sectional Area of Pipe	m	0.002826
Length of water	m	0.5
Width of water	m	0.32
Depth of water	m	0.15
Ar= w × d Cross-sectional area of the channel	m²	0.048
First reading of velocity	m/s	0.37
second reading of velocity	m/s	0.32
third reading of velocity	m/s	0.36
Vr Average stream flow velocity	m/s	0.35
Water Head	m	1.5
Vm=vr*1	m/s	0.35
Q = Vm× Ar	m^3/s	0.0168
The water flow rate	m^3/s	0.0168
Voltage produce	V	0.86
Current produce	A	0.006
Power produce	W	0.00516
Efficiency =power/density* height* Gravitational acceleration*water flow	%	0.002089

D. *Case 4: Testing using drainage water with high contamination.*

Fig.22. Case 4 Result

TABLE IV. Case 4 result: Testing using drainage water with high contamination.

	Units	Case 4
Gravitational acceleration	m/s	9.8
Density of water	Kg/m^3	1000.6
Radius of Pipe	m	0.03
Cross sectional Area of Pipe	m	0.002826
Length of water	m	0.5
Width of water	m	0.32
Depth of water	m	0.15
Ar= w × d Cross-sectional area of the channel	m²	0.048
Vr Average stream flow velocity	m/s	0.2
Water Head	m	1.5
Vm=vr*1	m/s	0.2
Q = Vm× Ar	m^3/s	0.0096
The water flow rate	m^3/s	0.0096
Voltage produce	V	0
Current produce	A	0
Power produce	W	0
Efficiency =power/density* height* Gravitational acceleration*water flow	%	0

As it can be seen from the above analysis hat with increasing contamination flow rate of water in water channel starts decreasing which reduces the turbine efficiency as well as the power output. The highest efficiency of turbine is obtained with tap water which is free of contamination while lowest efficiency was obtained with drainage water having high contamination. This is due to low flow rate at high contamination. Low flow rate produces less power thus reduces turbine efficiency. As all industries produce waste which is channelized through sewage pipes. The installation of Pico hydro turbines on these sewage pipes can produce electricity which will enable the industry to power the lights and other small power electrical devices. This will reduce the power consumption of industry reducing their electricity bill too. Less electricity bills mean the overall profit of industry will increase. Thus, Pico hydro turbines can help industry to increase their revenue. Also, it is renewable energy source so it will earn carbon credits for that industry.

VIII. RECOMMENDATION AND FUTURE WORKS

As far as future work and recommendations are concerned, mechanical power transmission of Pico hydro should be studied in detail. Smooth and with less friction operation of the turbine must be ensured. To ensure that the design is reliable for future energy production, a detailed study must be conducted on the dynamics and kinetics of design. To harness more energy the turbine efficiency is a key factor. The efficiency of the turbine can be enhanced by working on the design, shape, and manufacturing process of the turbine. Due to stress concentrations, right between the blades and base plate, the crack may be initiated thus design needs to be improved in this sense too. More research studies need to be conducted to overcome the challenges faced in efficiency of Pico-turbines and its commercialization. Future of Pico hydro not only lies in technical development but also it need developments in economics and policy.

Unlike rest of conventional energy sources, Pico hydro is green and clean source of energy which will contribute toward reduction in GHG, global warming and climate change. Pico hydro installation in remote areas will not only help to electrify that area but also will create jobs for local community. Government should contribute toward friendly policy for Pico hydro to remove barriers and encourage investment from private sector.

To get maximum out of Pico hydro projects, site visit and survey must be conducted to take in account the head and flow rate so that expected power outcome may be calculated. These surveys will help to make Pico hydro projects more economical.

Continuous inspection of Pico-hydro must be conducted and maintenance like greasing/lubrication of bearings must be brought into business to enhance the life time of project and reduce the power losses as well. There are many key points that ensures the bright future of Pico hydro. Few of them include high grid cost in remote areas, low head sites are ideal for Pico hydro, improved living standard of remote areas community and green energy conversion technology etc.

IX. CONCLUSION

Pico hydro turbines have great potential to electrify the rural and hilly areas. This paper was aimed to design a Pico hydro turbine which was installed on sewage pipelines to produce electricity for local population. The project was divided into three phases. In first phase sewage pipeline water quality was be tested in lab in term of pH, dissolved solids and suspended particle. As suspended particle and acidity of water could result in failure and corrosion of turbine. The theoretical power and energy available in sewage pipeline was be calculated. These results of first two stage phases were satisfactory thus taking into account the feasibility of project, the CAD design of turbine was developed using the solid works software. The turbine model then was manufactured and installed on sewage water pipeline. Pico hydro ipromising technology of the current scenario and future in terms of power generation and overcoming climate change issues. This technology without loss of mass flow rate in pipeline generates electricity. This technology only uses the kinetic energy of water. The designed project depicts that Pico hydro turbine installation in all the nations can help to reduce the load on the central grid as well as to mitigate the GHG emissions.

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