Design and Construction of a Micro-hydro Turbine for Additional Home Power to Use a Conventional Water Pipeline

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Abstract This paper covers the design and fabrication of a micro-hydro turbine that is using a conventional water pipeline to generate additional home power. The process started with identifying the suitable design and then uses the standard design as reference to develop the micro-hydro turbine. The project included computational fluid dynamics (CFD) simulation test that was run using ANSYS CFX. Data obtained from simulation test was used to verify the actual data that obtain from confirmation test.

Keywords Computational fluid dynamics · ANSYS CFX · Micro-hydro turbine Francis · Energy harvesting

1 Introduction

Since the beginning of civilisation, renewable and sustainable energy sources have been important for humans. For centuries, this type of energy source has been used in many ways such as biomass which has been used for heating, cooking, while for power generation, hydropower and wind energy has been used for mechanical

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movement. Then, this mechanical movement generated by hydropower and wind energy was used for electricity production. This project focuses more on the hydropower technology and development since it is the second most sustainable renewable energy after wind energy.

2   Problem Statement

A water storage tank will not only be used to save water, but it also has potential energy because it requires gravitational force for the distribution of daily use at home. Unfortunately, this energy is not fully utilized or ignored because the water pressure for household daily use it is not up to the maximum level.

Using micro-hydropower technology as reference, the potential energy of the water storage tank can be used to generate kinetic energy when water is falling into the distribution pipe pushing the turbine blades. Then the kinetic energy or hydropower from the turbine moves a dynamo that is connected to the turbine where the kinetic energy is converted into electrical energy.

3   Significance of the Project

The significance of this project is related to the installation of a micro-hydropower turbine within conventional water pipeline. This does not only offer alternative renewable and sustainable energy sources but it also utilizes all unused energy. Dependency on electricity from on-grid can be reduced and indirectly save money. The results obtained provide a platform for further investigation into our study which aimed at improving the efficiency of the micro-hydro turbine for commercial use of the combination with other renewable and sustainable energy sources such as wind energy and solar energy to create an independent off-grid hybrid power system.

4   Objective of the Project

The objectives of this project are as follows:

  i. Understand the stable turbines runner type, effects of water flow and buildings height to the power output from a micro-hydro turbine.
 ii. Design and construction of a prototype of a micro-hydro turbines that is able to supply additional electricity for standard household usage.
iii. The output obtained from turbine should be ranged 3–12 V of direct current (VDC).

5 Project Scope and Limitation

This project focused on the design and fabrication of a prototype micro-hydro turbine that is able to supply additional electricity for standard household usage by studying and comparing the type of turbine runner, in terms of performance and head. The design of the prototype is based on design consideration, facilities, cost and performance of the turbine runner and will not cover the electrical or electronic system for the micro-hydropower system. All parts for the electrical or electronic system in this project are commercial products.

6 Literature Review

The history of micro-hydropower started mostly for milling grain with the wooden waterwheel which are for some 2000 years, or waterwheels of various types that had been in use in many parts of Europe and Asia.

6.1 Micro-hydro Turbine

To date there is still no internationally agreed definition of term the micro-hydropower where other terms such as mini-, small- and pico- are also used for range diminishing capacity down to a few hundred watts [1].

6.2 Forms of Energy

Micro-hydropower is 'fuelled' by water moving in the hydrological cycle or water cycle (see Fig. 1) which is powered by solar energy. It happens when the converted heat from the solar radiation is reaching the surface of earth and evaporates water mostly at the sea. Some of the water vapour is brought over land areas where it later condenses into clouds and rain. Then some of the water flows back towards the sea because of precipitation on the land surface and this generates run-off, under the influence of gravity. Since the water cycle is powered by solar energy, therefore it makes micro-hydropower renewable and sustainable and will continues if the sun continue to shine [2].

As this 'water cycle' concept is applied to conventional piping systems in houses, the stored potential energy in the water storage tank in the house can be harvested to fuel micro-hydropower. Ramage [1] in her book describes that water (or anything else) held at height represents stored energy. To lift one kilogram vertically trough one metre against the gravitational force of the earth, about 9.81 J
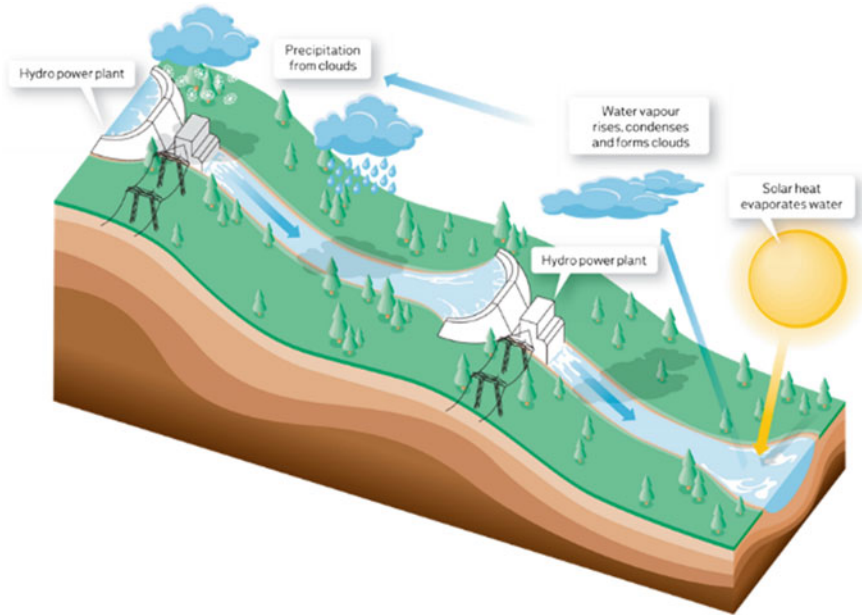
**Fig. 1** Natural water cycle

of energy input are needed (p. 155). Therefore, if *M* kilograms are raised through *H* metres, the stored potential energy in joules is given by;

$$Potential\ Energy = MgH, \tag{1}$$

where *g* is represents the acceleration due to gravity, whose value is about 9.81 ms^{-2}. *M* represents the water mass and *H* represents the height of water storage tank as shown in Fig. 2.

The Law of Energy Conservation as the First Law of Thermodynamics stated that "In any change from one form of energy to other forms, the total quantity of

Fig. 2 Water with potential energy
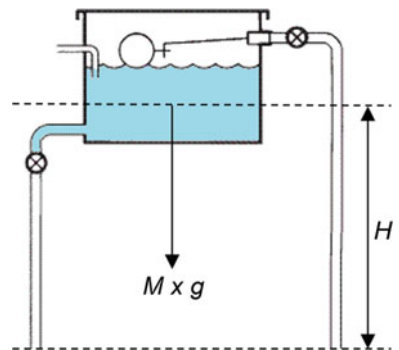
energy remains constant". Therefore, if energy is conserved, the potential energy loss by a freely falling object must appear as a gain in its kinetic energy, so an object that falls from rest (zero kinetic energy) through a height H will acquire kinetic energy [3].

6.3 Effects of Water Flow and Head to the Power Output

Micro-hydro turbines convert water falling into the distribution pipe (water pressure) into mechanical shaft power, which can be used to drive an electricity generator. The power available is proportional to the product of pressure head, volume water flow rate and must consider energy losses since in any real system frictional drag and turbulence will cause some energy loss to water [4]. The general formula for any hydro system's power output is;

$$P = \rho \times g \times H \times Q \times \eta, \tag{2}$$

where P is the mechanical power produced at the turbine shaft (watts), η is the hydraulic efficiency of the turbine, ρ is the density of water volume (kg/m^3), g is the acceleration due to gravity (ms^{-2}), Q is the flow rate passing through the turbine (m^3/s) and H is the effective pressure head of water across the turbine (m).

6.4 Turbine Runner

These two types of turbines use different mechanics to rotate the runner.

a. **Impulse Turbine Runner**—An impulse turbine operates into atmospheric pressure by using the kinetic energy of water jet to drive the runner and discharged to atmospheric pressure [5].
b. **Reaction Turbine Runner**—The reaction turbine is fully immersed in water and specifically enclosed in a pressure casing. The runner blades are designed to rotate caused by the pressure difference across them which impose the lift force [6].

6.5 Design Consideration

These considerations are;

i. **Flow rate measurement**. The volume flow rate Q of a fluid for this project taken from the water flow rate of a conventional water piping system.

ii. **Head of measurement**. Head of measurement, H for this project taken from the different height of the water storage tank to the height of installation location of the micro-hydro turbine and this value will be constant.

iii. **Diameter of inlet measurement**. Diameter of inlet measurement for this project taken from pipe diameter for distribution of conventional water piping system in the house. This value will be constant.

iv. **Turbine power**. Power in watt generated in the turbine shaft calculated using Eq (2).

v. **Turbine speed**. The turbine speed in RPM, to be determined using simulation test.

vi. **Type of turbine runner selection**—should be based on the low head and low flow rate since for this project, the current design of micro-hydro turbine will be compressed to be a smaller design to be compatible with conventional water piping system in the house.

vii. **Fabrication facilities**. The designed turbine runner should be able to be fabricated using common facilities in a current facilities in workshop.

7 Methodology

Figure 3 shows the steps of the project in brief which consist of the design stage, virtual simulation by virtual, fabrication of actual parts, assembly process and experimental comparison with actual design and simulation.
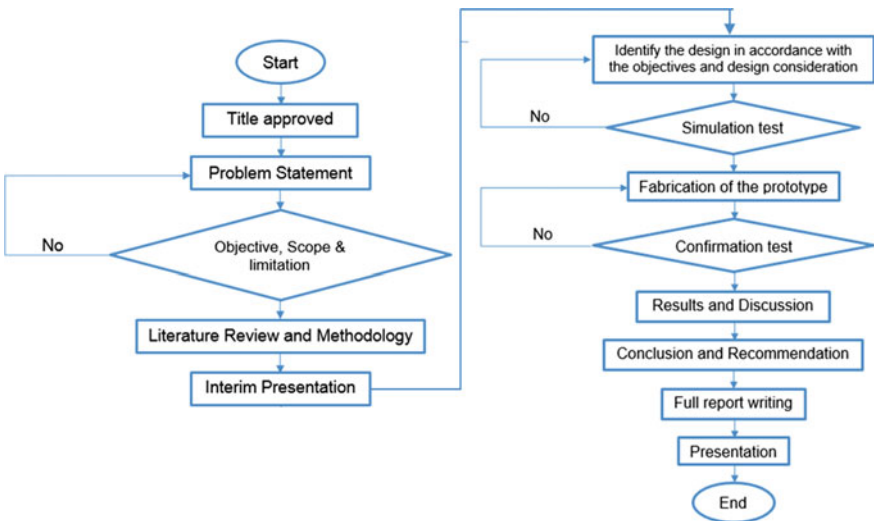

Fig. 3 Project flowchart

7.1 Designing Phase

In this process, the design of the micro-hydro turbine will be identified according to the objective and design consideration. It also includes information gathering and preparation for 3D modelling. After all data is collected, the 3D modelling process started according to the gathered information. Solidworks was used for the 3D modelling.

7.2 Simulation Test

After the 3D modelling process is done, a computational fluid dynamics (CFD) simulation test was run using ANSYS CFX. The output of this test was the required info to verify the confirmation test.

7.3 Fabrication of the Prototype

In this process, the G-code for generated tool path was generated to fabricate the prototype using a 3D printing machine. The process requires the use of a 3D model to tool path Slicer software which is the Cura and Stratasys Control Panel. Then the prototype was fabricated using two different models of 3D printers; the Odyssey X2 Series that uses Polylactic acid (PLA) as material for fabrication and the Stratasys FDM 200mc that uses Acrylonitrile butadiene styrene (ABS) as material for fabrication. Then, the finished parts were assembled.

7.4 Confirmation Test

Confirmation test is a process to verify the final output of prototype product with the theoretical data that was obtained from simulation test.

8 Results and Discussion

The design of the micro-hydro turbine also considered the characteristics from conventional pipelines as the boundary conditions. The limited space in house hold and low volume flow rate conventional water pipelines shows that the micro-hydro turbine requires a low head and low flow rate. The micro-hydro turbine was designed based on the standard design of the Francis turbine.
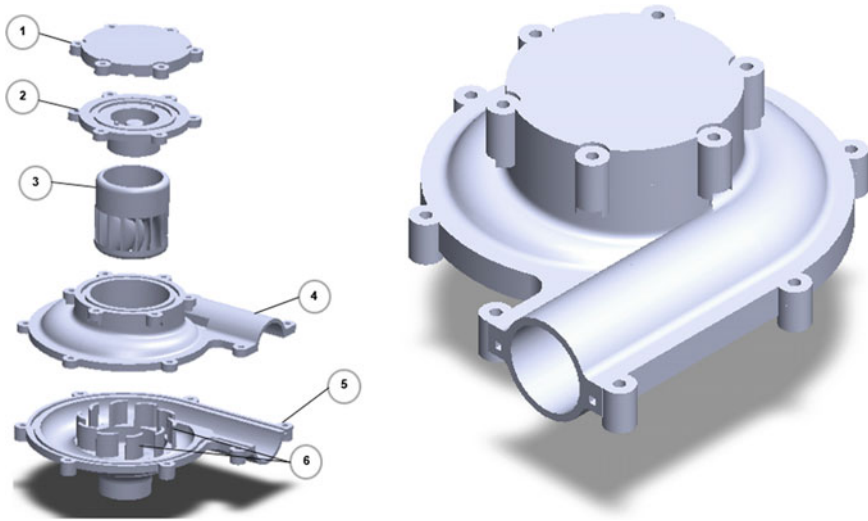
Fig. 4 Micro-hydro turbine assembly (on the right) and parts; (1) stator mount cover, (2) stator mount, (3) turbine rotor, (4) top spiral-casing, (5) bottom spiral-casing, (6) 'fixed' guide vanes

In standard design, the turbine runner is connected to the generator via a shaft. However, to reduce the space usage, the turbine runner and generator's rotor are combined. The inlet and outlet of the micro-hydro turbine are dimensioned according to a standard conventional pipeline. Figure 4 shows the exploded view and completed 3D model of the selected design.

8.1 Simulation Test

The relevant boundary conditions present during the measurements were reproduced in the simulations to ensure regularity of the comparison between computed and measured data. Computing hydraulic characteristics, CFD simulations give a detailed insight into the complex structure of the Francis turbine fluid flow, as shown in the following Figs. 5 and 6. The data computed from the CFD simulations were then sorted by percentage of valve opening as shown in Table 1.

8.2 Fabrication of the Prototype

The prototype was fabricated using two types of 3D printer machines with different types of materials. The reason for this were the time constraint, manufacturing feasibility and limited space of working area. The two types of material for
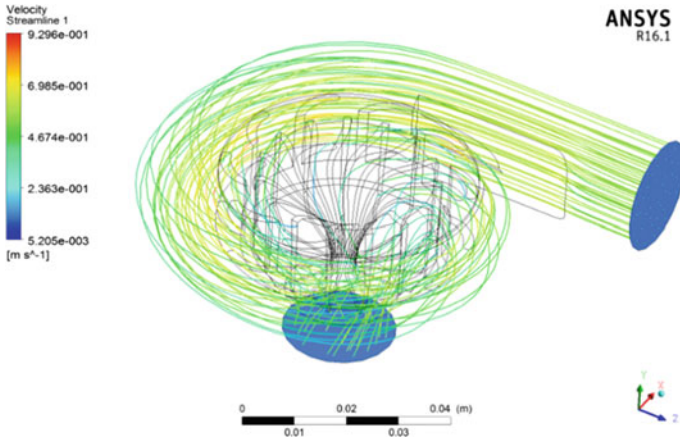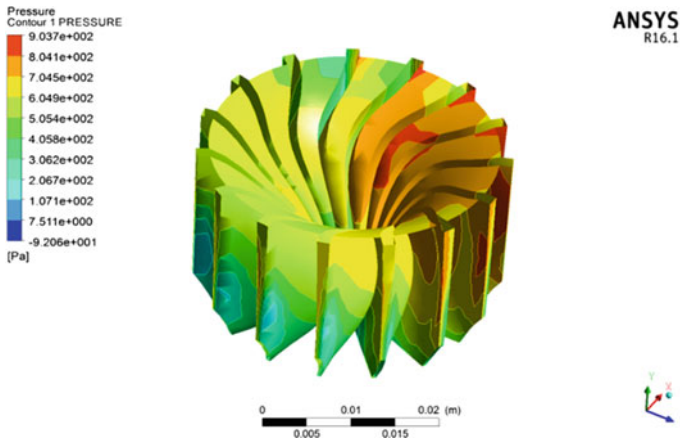
Fig. 5 Fluid flow streamlines

Fig. 6 Contours of static pressure on runner surfaces

Table 1 Analytical data from simulation test

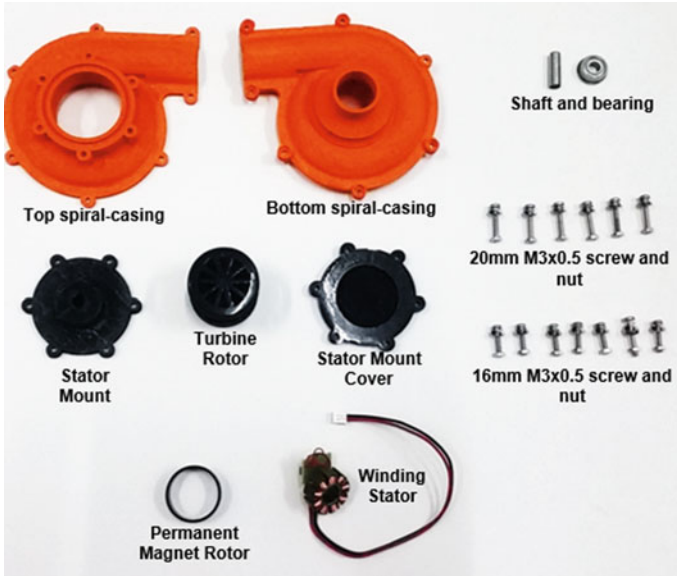| Percentage of valve opening (%)	Velocity, v (m/s)	Angular speed, ω (rad/s)	Torque, τ (Nm)	Mechanical power, P (W)
25	9.296E−01	4.893E+01	1.870E−02	0.914946568
50	1.719E+00	9.047E+01	2.057E−02	1.860862737
75	2.310E+00	1.216E+02	2.185E−02	2.657037379
100	3.577E+00	1.883E+02	2.197E−02	4.135751874

Fig. 7 Parts that required to assembly the micro-hydro turbine

fabrication are; Polylactic acid (PLA); in black and Acrylonitrile butadiene styrene (ABS), in orange. Despite the different types of the used materials, the quality of the fabricated parts was still the same in terms of tolerance and toughness.

Additional parts were required to complete the assembly of the micro-hydro turbine. Figure 7 shows all parts that were required to assemble the micro-hydro turbine including fabricated parts and commercial parts. The winding stator and permanent magnet were taken from the brushless motor in a commercial mini water pump.

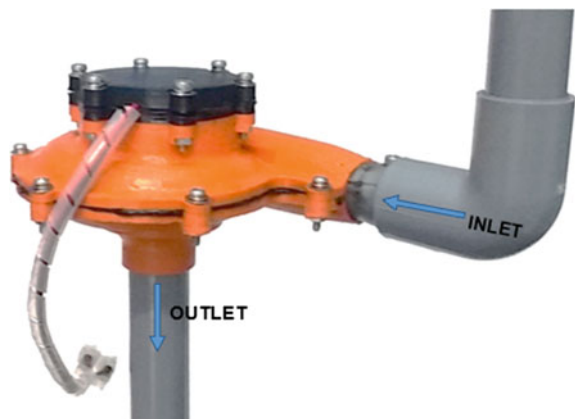**Fig. 8** Final product of micro-hydro turbine

Figure 8 shows the final product of the micro-hydro turbine that was connected to UPVC PIPE 15 mm (SIRIM QAS CERT TO MS6828 PT-1:1999) and ready to be connected to the conventional water pipeline.

8.3   Confirmation Test

The micro-hydro turbine was tested with the same setup as boundary conditions present during the measurements and were reproduced in the simulations. The data obtained during the test and compiled is shown in Table 2. The value of the power, P (watts) from Tables 1 and 2 were combined and compared as shown in Fig. 9.

Table 2 Analytical data from confirmation test

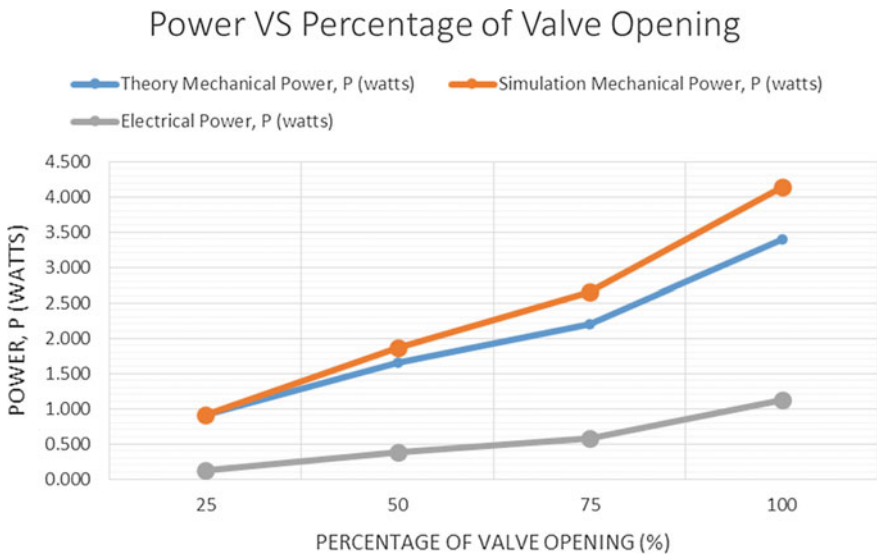| Percentage of valve opening (%)	Avg. voltage, V (V)	Avg. currents, I (A)	Electrical power, P (W)
25	0.690	0.17	0.117
50	1.702	0.22	0.374
75	2.425	0.24	0.582
100	3.229	0.35	1.130

Fig. 9 Comparison of computed and measured turbine power output

9   Conclusion

The results from the confirmation test in Fig. 9 show that the flow rate of the water that enters through the turbine runner will affect the speed of the turbine runner. This will directly affect the power output from a micro-hydro turbine since the speed of the generator is proportional to the speed of the turbine. This is because the generator is connected directly to the turbine runner.

The confirmation test result also has a significant difference with the theoretical result. However, the same data trend shows that the correct turbines runner type has been used. The significant difference may be caused by;

(1) fabrication defects,
(2) high surface roughness,
(3) Leaking that will reduce the flow rate, and
(4) Inconsistency of flow rate caused by the turbulence flow.

The prototype of the micro-hydro turbine is able to supply additional electricity for household usage however it cannot achieve maximum output as required in the objective. In conclusion, some of the objectives for this project were successful achieved but some are partly achieved and required further improvement.

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