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Pico Hydro Generator Module for Domestic Water Pipe Fitting

Muhammad Hifzhan Abdul Wahab[1], **Kok Boon Ching**[1*]

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Residents with B40 status, especially residents who have private homes, need a low cost of living and save money. To get electricity savings, an innovation can be done. The existence of water pipe flow in residential areas that is constantly flowing all the time can be used to be converted to electricity using hydro pico generator module for domestic water pipe installation so that it can be used to supply electricity to consumers. The output stability of the pico hydro generator module can be enhanced with a stabilizer in the form of a DC to DC converter system so that it can reach a stable voltage of 5 volts DC. In this final project, the DC to DC converter used is a buck-boost converter obtained from a permanent magnet DC generator in a pico hydro generator module system. The buck-boost converter circuit can produce a stable output voltage of 5 volts DC. A stable DC output voltage is then routed to the battery charger module with a frequency of 50 Hz. A predefined buck-boost converter circuit can work when given an input voltage between 2-8 volts. The test results of the whole system produced an average output voltage of 4.98 until 5.12 volts with an average output current of 0.12 amperes.

Keywords: Hydro Generator, Water Pipe Fitting, Electricity

1. Introduction

Hydroelectric is clean, non-polluting and a renewable source of energy. It utilises the water which will be reused for another purpose. By moving the turbine with the help of water, electricity is produced. It is done by converting kinetic energy and the potential energy of water into useful forms of energy. It is the oldest technology available for power generation [1]. However, electricity is a very important energy in modern civilization that shows most appliances need an electric supply to operate. It helps humankind to be more productive and improves the quality of living [2]. By the way, it is vital to find new ways for electricity generation, especially for residential areas that accost-effective and sustainable [3].

**Corresponding author: bckok@uthm.edu.my*

Thus, this project aims to utilise hydro energy and convert it into useful electric energy by designing a pico hydropower module [4]. A pico hydropower system needs a turbine or waterwheel and generator to transform the energy of flowing water into rotational energy, which is converted into electricity [5].

Micro hydropower is a type of hydroelectric power that uses the natural flow of water to the generator between 5 kW and 100 kW of electricity [6]. Contradictorily, pico hydro is defined as hydroelectric power generation of under 5 kW [7]. These generators have shown to be beneficial in small, rural villages with limited electrical needs. However, society does not realise that were having wasted the energy of water flow from household pipelines. Hence, an innovative design of pico hydroelectric generation module will be proposed in this project to harvest the waste kinetic energy from the continuous flowing of treated water in residential pipelines.

The water flow rate at some residential areas is not consistent. This problem will cause many implementation issues on a typical pico hydroelectric module such as over speed and ineffective generation. Therefore, this project is devoted to proposing appropriate design parameters that can further improve the functionality of the pico hydroelectric power module. Taking into consideration the above-mentioned issues, it is possible to increase the efficiency by using low and high pressure water energy systems. The major technical parameters of the hydro turbine are the water flow velocity and water volume.

A typical DC mini water turbine generator can only produce up to 1.8 Watt of power [8] that can just be used to light up LED [9]. Therefore, this project will improve this issue for at least the pico hydro generation module can charge a Lithium-Ion rechargeable battery.

The main objective of this research is to design a pico hydropower module that can be embedded into an existing residential distribution pipeline. Its measurable objectives are as follows: to perform comprehensive modelling and simulation works of a pico hydropower system, to control the generated voltage due to inconsistent water flow rate of residential pipeline and to apply an appropriate energy charging and storage circuits for the pico hydropower module.

2. Materials and Methods

The methods used to develop pico hydropower system that can be embedded into an existing residential distribution pipeline and charge 3.7V 1300mAh Lithium Ion rechargeable battery will be describe. This methodology helps to ensure that the project progress will be as the planned. Moreover, any problem occurs can be solve in order to achieve the project objectives. The flow how the project work is illustrating by step using flowchart. After that, the simulation and outcome of this project are built and acquired by putting together the necessary components needed in MATLAB Simulink. Therefore, all the sequence used in order to ensure the objectives are achieved as well as obtaining an excellent result.

2.1 Work Flow of Project

The aim of this project is to generate a power supply for charging batteries using pico hydropower system. The overall process and procedures of this system are illustrated by a flowchart as shown in Figure 1. The work starts by identifying the problem statement. Then, the tools needed in designing this project is determined. After implementing the pico hydropower system, the result obtained is used for the analysis and discussion.

2.2 Project Flow Design

The process for designing this project is shown in Figure 2. Every important aspect to make sure this project functions for solving the problem is clearly described through the flowchart.

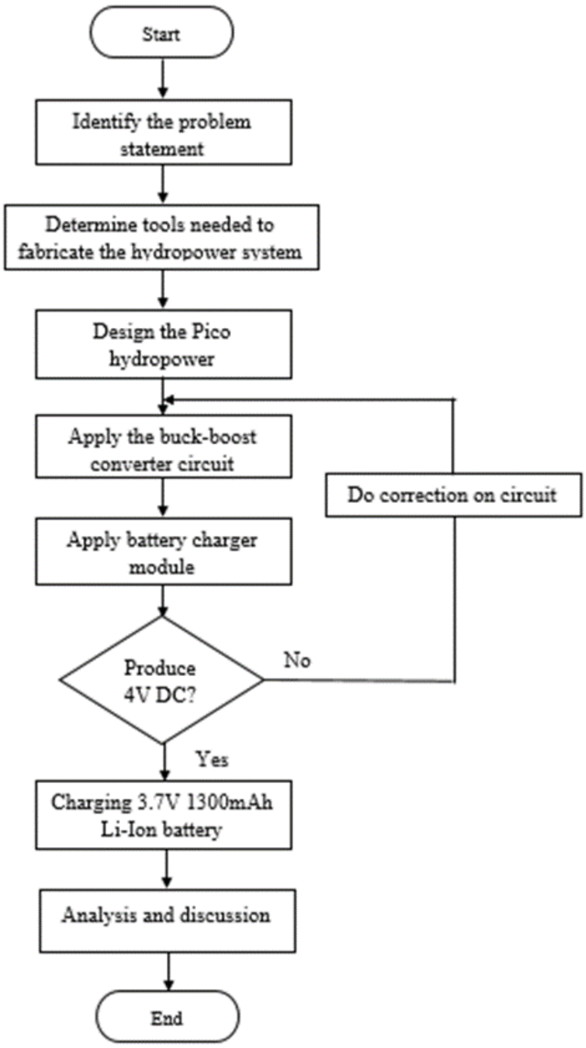

Figure 1: Workflow to generate a power supply for charging the battery using pico hydropower system

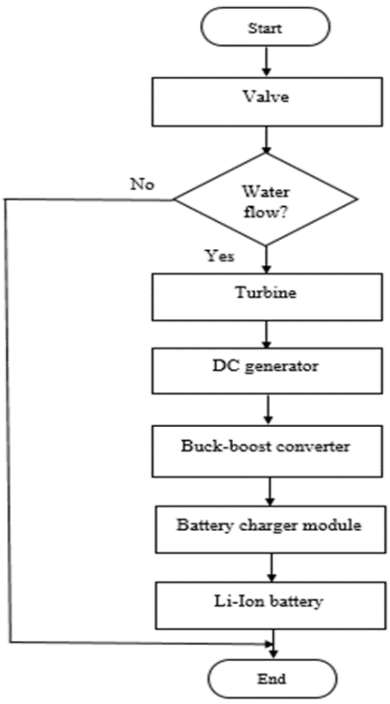

Figure 2: The flowchart in designing the project

2.3 Buck-Boost Converter

The output voltage of a buck-boost converter can be less than or larger than the input voltage. The output voltage polarity is opposite that of the input voltage. An inverting regulator is another name for this converter. Figure 3 depicts the circuit layout of a buck-boost converter.

There are two modes of functioning for the circuit. During mode 1, the MOSFET is used as a switch, and the diode Dm is reverse biased. The rising input current passes through inductor L and the MOSFET. During mode 2, MOSFET is switched turned OFF, and the current flowing through inductor L is diverted to L, C, Dm and the load. The energy stored in inductor L would be transmitted to the load, and the inductor current would decrease until the next cycle when the MOSFET would be switched ON again. Figure 4 depicts the comparable circuit for the modes.

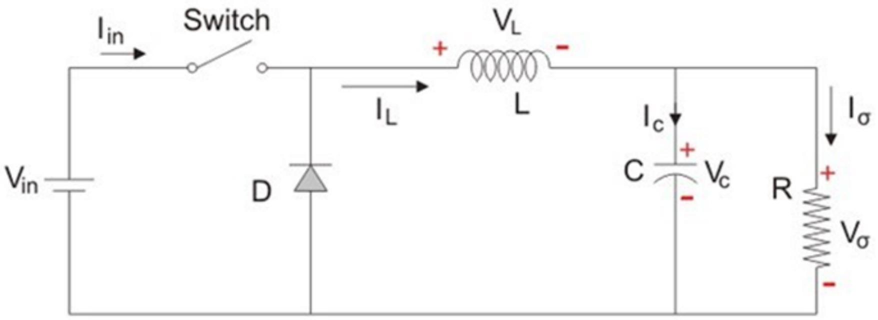

Figure 3: Buck-boost converter schematic

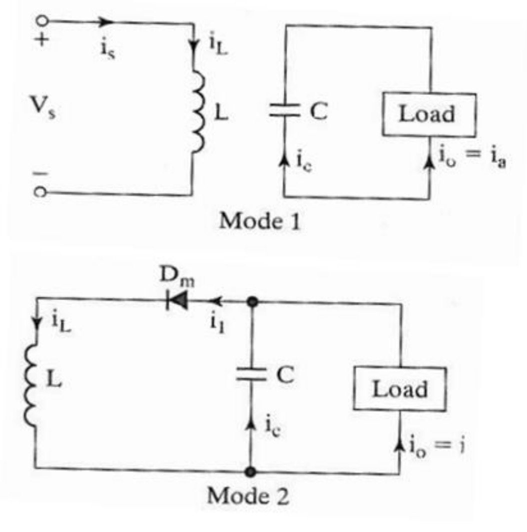

Figure 4: Equivalent circuit of Buck-boost converter

The rate of change of inductor current is constant, indicating that the indicator current is linearly increasing. The previous equation can be written as

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_s}{L} \qquad \textit{Eq. 1}$$

Solving for Δi_L when the switch is closed

$$(\Delta i_L)_{closed} = \frac{V_s DT}{L} \qquad \textit{Eq. 2}$$

Analysis of the open switch. The current in the inductor cannot change instantaneously while the switch is open, resulting in a forward-biased diode and current into the resistor and capacitor. The voltage across the inductor is at this point is

$$v_L = V_O = L\frac{di_L}{dt} \qquad \textit{Eq. 3}$$

$$\frac{di_L}{dt} = \frac{V_O}{L} \qquad \textit{Eq. 4}$$

Inductor current is changing at a constant rate, and the current changes at a constant rate are

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_0}{L} \qquad \textit{Eq. 5}$$

Solving for Δi_L

$$(\Delta i_L)_{open} = \frac{V_0(1-D)T}{L} \qquad \textit{Eq. 6}$$

When utilizing using Equations (2) and (6), the net change in inductor current in inductor current over one period must be zero for steady-state operation.

$$(\Delta i_L)_{closed} + (\Delta i_L)_{open} = 0$$

$$\frac{V_s DT}{L} + \frac{V_O(1-D)T}{L} = 0 \qquad \textit{Eq. 7}$$

Solving for V_O,

$$V_O = -V_s\left[\frac{D}{1-D}\right] \qquad \textit{Eq. 8}$$

Eq. 8 demonstrates that the output voltage is polarized in the opposite direction as the source voltage. Depending on the duty ratio of the switch, the output amplitude of the buck boost converter can be less than the source or more than the source. The output is larger than the input when $D > 5$,, and output is smaller than the input when $D < 5$.

In the buck boost converter, the supply is never directly connected to the load. When the switch is closed, energy is stored in the inductor and delivered to the load when switch is opened. As a result, buck boost converters are also known as indirect converters.

The amount of power absorbed by the load must be the equal to the amount of supplied by the source,

Where

$$P_O = \frac{P_O^2}{R} \qquad \textit{Eq. 9}$$

$$P_s = V_s I_S \qquad \textit{Eq. 10}$$

$$\frac{V_O^2}{R} = V_S I_S \qquad \textit{Eq. 11}$$

Average inductor current is related to average source current by

$$I_S = I_L D \qquad \textit{Eq. 12}$$

Resulting in

$$\frac{V_O^2}{R} = V_S I_L D \qquad \textit{Eq. 13}$$

Substituting for V_O using equation (8) and resolving

$$I_L = \frac{V_O^2}{V_S DR} = \frac{P_O}{V_S D} = \frac{V_S D}{R(1-D)^2} \qquad \textit{Eq. 14}$$

Maximum and minimum inductor current is determined using equation (2) and (14)

$$I_{max} = I_L + \frac{\Delta i_l}{2} = \frac{V_S D}{R(1-D)^2} + \frac{V_S DT}{2L} \qquad \textit{Eq. 15}$$

$$I_{min} = I_L - \frac{\Delta i_l}{2} = \frac{V_S D}{R(1-D)^2} + \frac{V_S DT}{2L} \qquad \textit{Eq. 16}$$

The inductor current must remain positive for continuous current to flow. To determine the boundary between continuous and discontinuous current I_{min} is set to zero in Equation (16),

$$(LF)_{min} = \frac{(1-D)^2 R}{2} \qquad \textit{Eq. 17}$$

Or

$$L_{min} = \frac{(1-D)^2 R}{2f} \qquad \textit{Eq. 18}$$

When F is switching frequency in *hertz*. The capacitor current waveform is used to calculate the output voltage ripple for the buck boost converter.

$$|\Delta Q| = \left(\frac{V_O}{R}\right) DT = C\Delta V_O \qquad \textit{Eq. 19}$$

Solving for ΔV_O,

$$V_O = \frac{V_O DT}{RC} = \frac{V_O D}{RCF} \qquad \textit{Eq. 20}$$

$$\frac{\Delta V_O}{V_O} = \frac{D}{RCF} \qquad \textit{Eq. 21}$$

Table 1 tabulated the parameter of the buck-boost converter based on the calculation.

Table 1: Buck Boost Converter Calculation Parameter

P (power)	4Watt
Vin (minimum input voltage)	2V
Vin (maximum input voltage)	8V
Vout (desired output voltage)	5V
Output Voltage Ripple	1%
Ripple Current Inductor	10%
Io	1A
R (Load)	10 Ω

The following is the calculation to determine the value of the components used:

1. Calculation with 2V input

a. Determine the duty cycle value

$$Vo = \frac{1}{(1-D)} Vi \qquad \textit{Eq. 22}$$

$5 = \frac{1}{(1-D)} 2$

$D = 0.6$

b. Determine the inductor value

$Io = Ic = 1A$

$Il = Io + Ii = 1 + 1 = 2\ A$

$$L = \frac{Vi \times D}{\triangle Ilpp \times fsw} \quad \textit{Eq. 23}$$

$L = \frac{2 \times 0.6}{0.1 \times 2 \times 15000}$

$L = 40\ mH$

c. Determine the capacitor value

$$C = \frac{Io \times D}{\triangle Vcpp \times fsw} \quad \textit{Eq. 24}$$

$C = \frac{1 \times 0.6}{0.01 \times 5 \times 15000}$

$C = 80\ mF$

2. Calculation with 8V input

d. Determine the duty cycle value

$$D = \frac{Vo}{Vi} \quad \textit{Eq. 25}$$

$D = \frac{5}{8}$

$D = 0.625$

e. Determine the inductor value

$$L = \frac{Vo \times (1-D)}{\triangle Ilpp \times fsw} \quad \textit{Eq. 26}$$

$L = \frac{5 \times (1-0.625)}{0.1 \times 2 \times 15000}$

$L = 63\ mH$

f. Determine the capacitor value

$$C = \frac{\triangle Ilpp}{8 \times \triangle Vcpp \times fsw} \quad \textit{Eq. 27}$$

$C = \frac{0.1 \times 2}{8 \times 0.01 \times 5 \times 15000}$

$C = 0.3\ uF$

From the calculation of the buck-boost converter, the smallest inductor value is $40\ mH$ and the largest capacitor value is $80\ mF$.

3. Results and Discussion

Hardware of this project has been developed by referring to the circuit designed in the previous chapter. Figure 5 shows the view of this project hardware. All the components used linked together in order to have a precise test results. Starting from water flow in domestic pipe line, valve of water flow control, dc generator, then the output voltage enters buck-boost converter. The buck-boost converter is used to stabilise the output voltage of dc generator, so that it can be stable at a voltage 5V dc to supply battery charger module, then charged the 3.7V 1300 mAh lithium ion battery. Figure 6 shows battery charger module at charging condition and Figure 7 shows battery charger module at full charged condition.

Figure 5: Top view of Pico hydro generator module

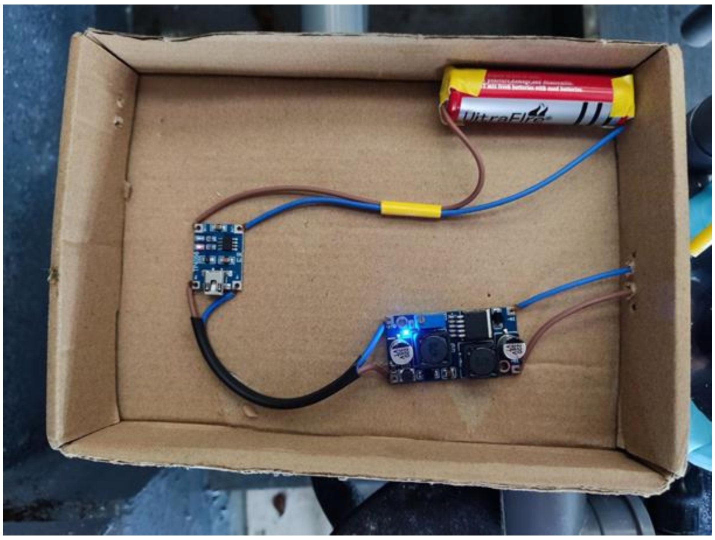

Figure 6: Battery charger module at charging condition

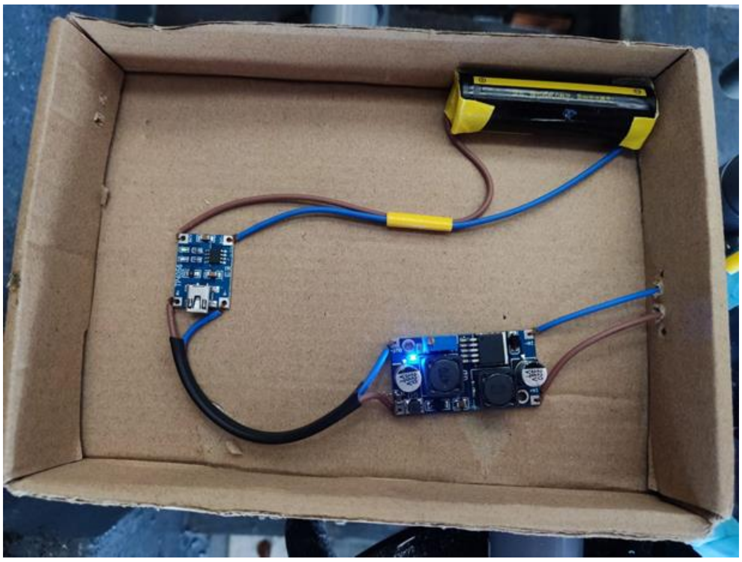

Figure 7: Battery charger module at full charged condition

The overall test was carried out by passing various amount of water flow through the generator. The amount of water flow can be set by adjusting the 90° valve water flow control. Valve was set from 40° of valve and increase constantly 40° until up to 90° of valve control shown in Figure 8.

Figure 8: Adjusting valve of water flow control through Pico hydro generator module

The output voltage of a DC generator varies depending on the amount of water flow applied. Table 2 shown the overall test results of buck-boost converter on the pico hydro generator module.

From the data collected in Table 2, when the larger amount of water flow, the larger output voltage of DC generator. 4.26 V is the maximum voltage produced at maximum openings of valve water flow. The average output voltage from battery charger module is 4.15 V that very suitable to charge 3.7 V 1300 mAh lithium ion battery. According to the result of the tests, the battery charger module can perform successfully if the buck boost converter output approaches or exceeds 5 volts.

Table 2: Overall test result of buck-boost converter on pico hydro generator

Valve of water flow Control (°)	Output Voltage DC Generator (V)	Output Voltage buck boost converter (V)	Output voltage battery charger module (V)
40	2.15	4.99	4.11
50	2.51	5.01	4.09
60	3.08	5.02	4.15
70	3.62	5.08	4.13
80	3.80	4.98	4.11
90	4.26	5.11	4.16

4. Conclusion

Water consumption at home can be used to generate electricity by installing a pico hydropower generator. At the end of this study, all the objective of this project is achieved and considered successful with all the result obtained. Able to perform a comprehensive modelling and simulation works of pico hydropower system. Besides, the output voltage using dc generator that has been connected to a turbine and flowing with water, the average output voltage of buck-boost converter reaches 4.98V and 5.12V due to inconsistent water flow rate of residential pipeline. Last but not least, this system constantly supplies 5V voltage to battery charger module to charge 3.7 Li-Ion battery that suitable for the electronic loads such as laptop battery packs, telephones, electronic cigarettes, flashlights and cordless power tools. This project will help to save electricity bills and can benefit other.

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References

[1] Yan, Z.G., Cui, T., Zhou, L.J., Zhi, F.L. and Wang, Z.W., 2012, November. Study on safety operation for large hydroelectric generator unit. In *IOP Conference Series: Earth and Environmental Science* (Vol. 15, No. 2, p. 022022). IOP Publishing.

[2] Markandya, A. and Wilkinson, P., 2007. Electricity generation and health. The lancet, 370(9591), pp.979-990.

[3] Borenstein, S., 2012. The private and public economics of renewable electricity generation. Journal of Economic Perspectives, 26(1), pp.67-92.

[4] Henderson, D., 1998. An advanced electronic load governor for control of micro hydroelectric generation. IEEE Transactions on Energy Conversion, 13(3), pp.300-304.

[5] Anaza, S.O., Abdulazeez, M.S., Yisah, Y.A., Yusuf, Y.O., Salawu, B.U. and Momoh, S.U., 2017. Micro hydro-electric energy generation-An overview. American Journal of Engineering Research (AJER), 6(2), pp.5-12.

[6] Gokhale, P., Date, A., Akbarzadeh, A., Bismantolo, P., Suryono, A. F., Mainil, A. K., & Nuramal, A. (2017). A review on micro hydropower in Indonesia. Energy Procedia, 110, 316-321.

[7] Basar, M. F., Ahmad, A., Hasim, N., & Sopian, K. (2011, December). Introduction to the pico hydro power and the status of implementation in Malaysia. In 2011 IEEE Student Conference on Research and Development (pp. 283-288). IEEE. Maryam Al Kaabi, & Dr.Ali Alhumairi. (2016). Automated Irrigation System. 5-15.

[8] Zeb, S., Ali, M., Mujeeb, A., & Ullah, H. (2019, January). Cost efficient Mini hydro plant with low water head whirlpool design methodology for rural areas:(Micro Hydro Whirlpool power plant). In 2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET) (pp. 1-7). IEEE.

[9] Sivasambua, M., & Alib, N. Production of Energy from Water Flow Output in Fish Tank.