Fuzzy Logic-Based Load-Frequency Controller Using Arduino for Hybrid Off-Grid Pico-Hydropower Systems

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Fuzzy Logic-Based Load-Frequency Controller Using Arduino for Hybrid Off-Grid Pico-Hydropower Systems

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***Abstract*—Hydroelectric power is one of the most abundant and efficient sources of renewable energy. Utilization of these resources by means of power generation is widespread around the globe as it provides sufficient amount of power at an environment-friendly cost. However, off-grid hydropower generation needs parameter regulations to ensure safety and standards of power production. Therefore, in this study, a load-frequency controller was designed based on fuzzy logic algorithm to regulate and maintain the load-frequency generated by this power system to 60 Hz with +/- 10% tolerance. Fuzzy Logic Algorithm is based on the degrees of truth rather than the Boolean or binary logic which is true/false or 1/0, which allows it as the more ideal to be used rather than the conventional PID algorithm in frequency control. Fuzzy set of rules are established to monitor the fluctuations. Arduino is used as the microcontroller which converts the commands for the servo motor to perform. It serves as the command center that navigates the servo motor for the control of the water flow whenever rising or dropping of load-frequency is detected. The servo motor then adjusts the valve to a certain degree to achieve the desired amount of load-frequency as set in the fuzzy rules. When the detected load-frequency is within its limits, the controller allows the servo motor to remain in its current position to maintain its produced power. The study proved that maintaining the required frequency of 60 Hz within 10% tolerance is necessary.**

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***Keywords*—Frequency controller, Fuzzy Logic, Load-Frequency, Frequency ontroller, Off-Grid, Pico-hydro**

I. Introduction

Renewal energy, such as hydropower, is in demand nowadays because it is abundant and environmentally-friendly. Hydropower generators play a major part in the utilization of renewable energy [1]-[4]. By using renewable energy, local villagers can enjoy the benefits of an improved way of living giving them more time for personal pursuits. With the use of the pico-hydropower generation system, we can create abundant energy from our environment [2]-[5].

Each power plant generates electrical power. During the maximum load conditions, all power plants share electrical power through Tie-line control. Load-Frequency control (LFC) is one of the most significant tasks in electrical power system design. Since the load of the power system demand varies with no previous plan, using a load-frequency controller can decrease these differences with no frequency uncertainties. Because of that, frequency controllers are needed to sustain or generate power quality to generate constant voltage and frequency to the power systems. The frequency can be regulated by load-frequency controllers, which regulates generator loadings.

Many studies and researches have been made and several methodologies have been developed with regards to load-frequency control. Differential evolution (DE) by tuning the proportional integral, integral, and proportional integral derivative parameters were used in load frequency control of three different sources of energy [6]. Meanwhile, in a micro-hydro power generation system, a fuzzy logic algorithm was used [7]. Lastly, for an island micro-hydro power plant, a ballast load method was used [8]. In this paper, a low-cost fuzzy logic-based load frequency controller using Arduino for a pico-hydro generator is proposed to be deployed and adopted by the rural communities. A pico-hydro generator has a low power than a micro-hydro generator [2].

The purpose of the low frequency controller is to regulate stable system frequency which does not have steady state errors and to deliver load sharing with multi areas interconnected in the power system using different algorithms. Some useful algorithm are Particle Swarm Optimization (PSO), Proportional Integral-Derivative (PID) and Fuzzy Logic. In this study, Fuzzy Logic is used. This algorithm deals with the Fuzzy set theory which offers a procedure to allow modeling of the systems that are complex or not described by mathematical statements. Similarly, fuzzy logic controllers are based on fuzzy set theory which is utilized to characterize the "experience of a human operator in terms of linguistic variables that are called fuzzy rules." With the application of fuzzy set theory, rules which are referenced on the methods made by human operators do not also need a system's mathematical model. Fuzzy logic-based controllers provide a mathematical basis for estimated reasoning, which has been very successful in many applications [9].

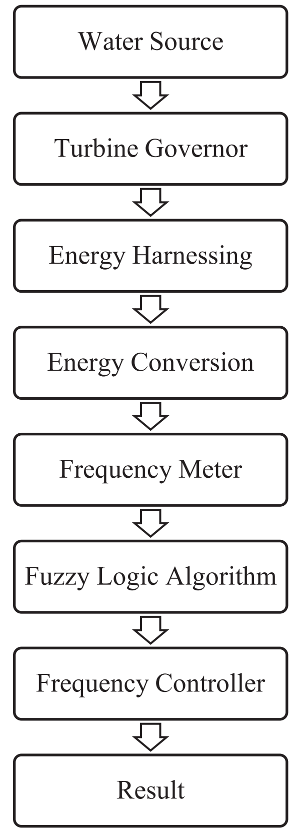


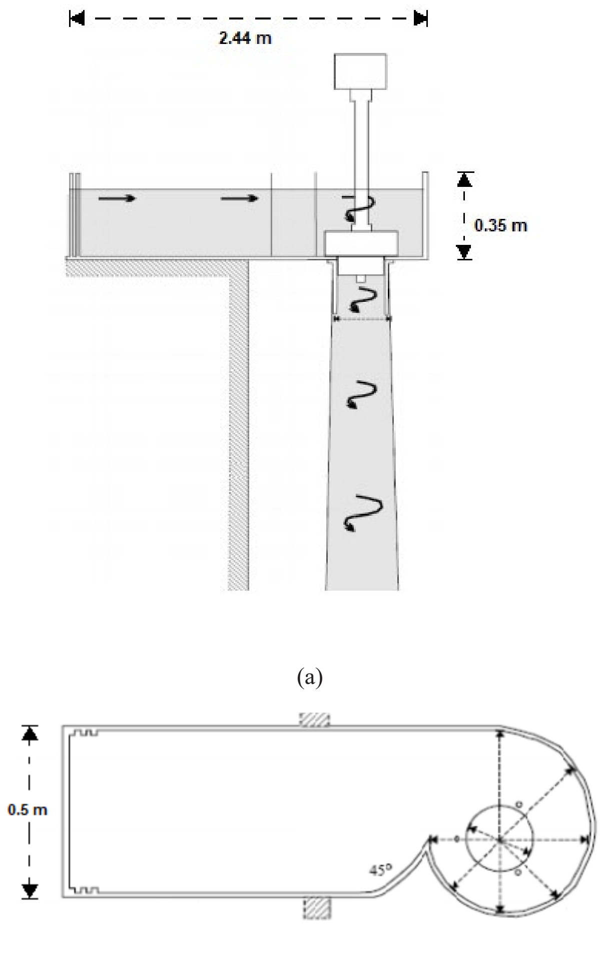
Fig. 1. General Framework

II. Methodology

The general framework shows the stages that the system undergoes to stabilize the frequency of the pico-hydropower system. First, the water enters the waterway through a gate that is being controlled by the servomotor. Initially, this gate opens to let the water enter which then drives the turbine for energy harnessing as a form of a turbulent. This turbine is coupled to a generator that will translate this mechanical energy to electrical energy. A meter, which reads the frequency, sends signal to the Arduino when the frequency is not stable to 60 Hz with 10% tolerance. The Arduino then sends a signal to the servomotor to open or close the gate based on the reading on the frequency meter. Fuzzy Logic Algorithm then precisely calculates the opening of the gate to make sure that the system frequency is stabilized.

A. Water Source and Water Canal

Water comes from the falls in Barangay Magsaysay, Atimonan, Quezon and is being collected through a water canal that flows as a turbulent. The water canal has a gate that opens and closes to control the water as it enters the waterway. It is made out of aluminum sheets with dimensions of 2.44 m length, 0.5 m width and sidewalls height of 0.35 m. Its vortex is 0.8 m while the gate is 0.49 m by 0.35 m. The gate has screen to filter leaves and other debris from entering the waterway and avoid the turbine from malfunctioning. Fig 2 and Fig 3 shows the design and actual assembly of the water canal.



(a)

(b)

Fig. 2. (a) Design of Water Canal (b) Top View

Fig. 3. Actual assembly of the Water Canal

B. Turbine Governor

The water needs to be controlled to achieve the correct amount that it needs to enter the turbine. Servomotor is used as a governing system or turbine governor which specializes for high-response, high-precision positioning. As a motor which has the ability to maintain accuracy in rotation angle and speed control, it can be utilized to adjust the gate at its accurate opening position. This servomotor is the central mechanism which is being controlled by the frequency controller that sends signals when the system needs more frequency or when there is shortage. The turbine governor modifies the water flow by adjusting the gate opening to control its speed or power output [10]. It may also adjust the generating unit's speed and system frequency. The primary functions of the turbine governor are as follows: i) Initially opens the gate so the water flows to the turbine ii) Partially opens the gate when the output frequency is below 60 Hz iii) Partially closes the gate when the output frequency is above 60 Hz. Fig 4 shows the servomotor used in the system. It has 95 degrees rotation clockwise and counterclockwise.

Fig. 4. Servomotor

C. Energy Harnessing and Conversion

As the water flows, it enters the turbine and rotates it. The turbine harnesses the energy from the rotation of the blades. It is coupled to a low-head generator that generates electrical energy. The generator is also suitable for mini falls. However, this is a critical factor because it needs enough water flow. The generator's requirement is low-rpm, low head and low water flow. Its rated power output is 200W with 250W maximum allowable load and intended voltage is 220V [11]. Rotor runaway speed is 1500 rpm. Fig 5 shows the turbine used.

Fig. 5. Turbine

D. Frequency Meter

After generating electricity, the frequency is measured. Due to waterpower variations and load demand, there will be fluctuations in the frequency [12] that will be monitored by the frequency meter. This frequency meter sends an input signal to the frequency controller whenever the output frequency is not 60 Hz. (Consider tolerance +/- 10 %)

E. Fuzzy Logic Algorithm

Fuzzy logic is a method referenced on the "degrees of truth" instead of binary or Boolean Logic. It assumes to manage the concept of partial truth, either completely true or completely false under certain circumstances. This is suitable for the automation of the control of water as fuzzy logic is comparable to human language. Fuzzy Logic Algorithm is used to precisely compute for the partial opening or closing of the gate in the water canal. The process is divided into fuzzification module, knowledge base, interface engine, and defuzzification module. In the fuzzification module, the range of values or traits of an object is set and converts it into fuzzy sets. The Knowledge base stores the If-Then statements. Meanwhile, an interface engine stimulates and processes the given inputs. Lastly, the defuzzification module converts fuzzy sets into crisp outputs that can easily be transmitted to the frequency controller. Fig 6 shows the Fuzzy Logic Toolbox in MATLAB [13].

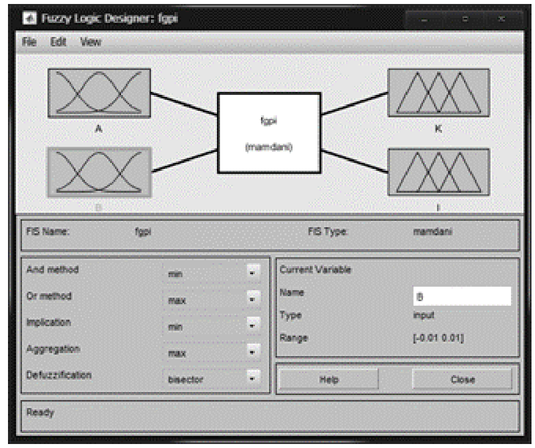


Fig. 6. Fuzzy Logic Toolbox in MATLAB

F. Frequency Controller

Load Frequency Control (LFC) is an essential constituent in power system process and regulation for supplying adequate and consistent electric power. The aim of the LFC is to stabilize the system frequency to 60Hz (vary in different countries). It controls the mechanism of the servomotor that adjust the opening and closing of the gate in the water canal. As the frequency meter reads the system frequency, it sends signal to the Arduino Uno which is the microcontroller used. This microcontroller together with the Fuzzy Logic Algorithm processes this data and sends an output signal which is the precise degree of rotation of the servomotor. Figure 7 shows the Load Frequency Control Assembly.

Fig. 7. Load frequency controller actual view

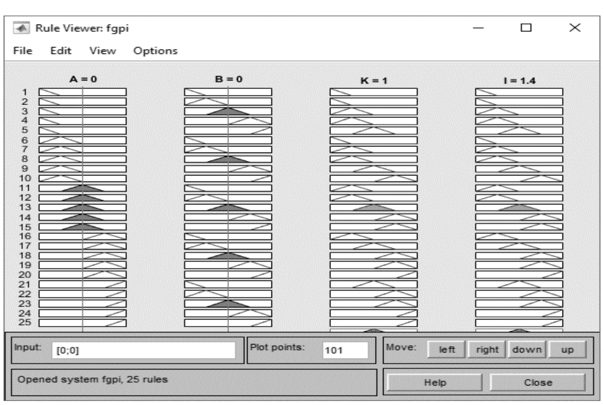
III. Design Considerations

Arduino Uno as a microcontroller is easy to understand and to integrate with the MATLAB Fuzzy Logic functions. Fuzzy Logic Algorithm is available in MATLAB and the interface can easily be used. It automatically calculates precise measurement once you enter correct input variables and logical rules [14]. The project mainly focuses on the automation of the gate control that is initially done by human operator. The design of the pico-hydropower system is suitable in falls and streams like in Barangay Magsaysay, Atimonan, Quezon. The project consists of the water canal, gate, servomotor (turbine governor), hydro turbine, synchronous generator, load frequency control (Arduino Uno) and frequency meter with display.

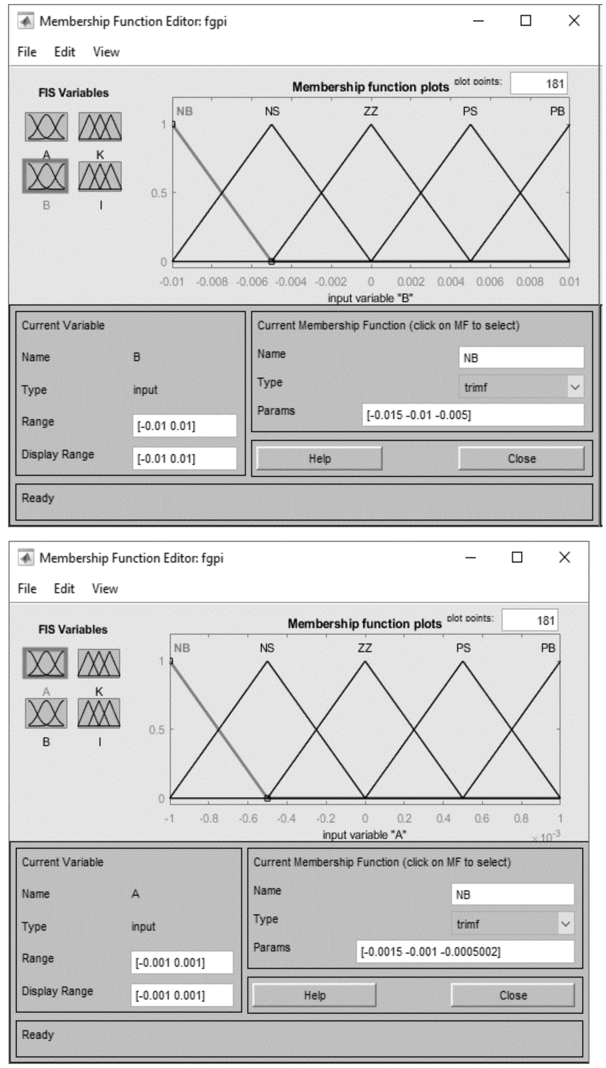
IV. Data and Results

To design a load frequency control consistent and intelligent, it must depend on not only accurate pico-hydro modeling, but also on an "expert knowledge base". The expert knowledge base consists of data on turbine process and regulation collected from expert technical specialist or professionals who are involved in field trials, simulation and predictions.

Fuzzy Logic Algorithm translates "these numerical variables into linguistic variables" [15], fuzzy sets are selected for inputs: negative big (NB), negative small (NS), zero (ZZ), positive small (PS), and positive big (PB); and five fuzzy sets are chosen for the output: small (S), medium (M), big (B), very big (VB) and very big (VVB). Input is the output frequency measured by the frequency meter and output is the degree of opening of the servomotor. Figure 8 shows the preferences used in MATLAB Fuzzy Logic Toolbox.



(a)



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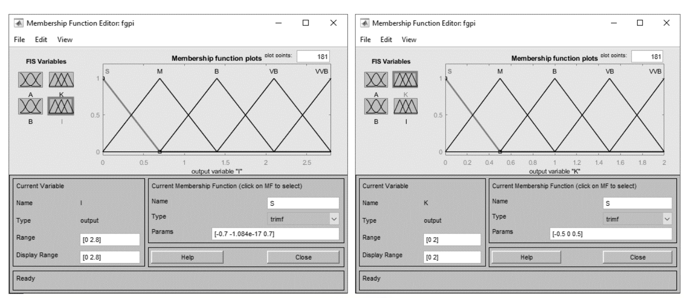

(c)

Fig. 8. (a) Input Membership Functions (b) Output Membership Functions (c) Rule Viewer

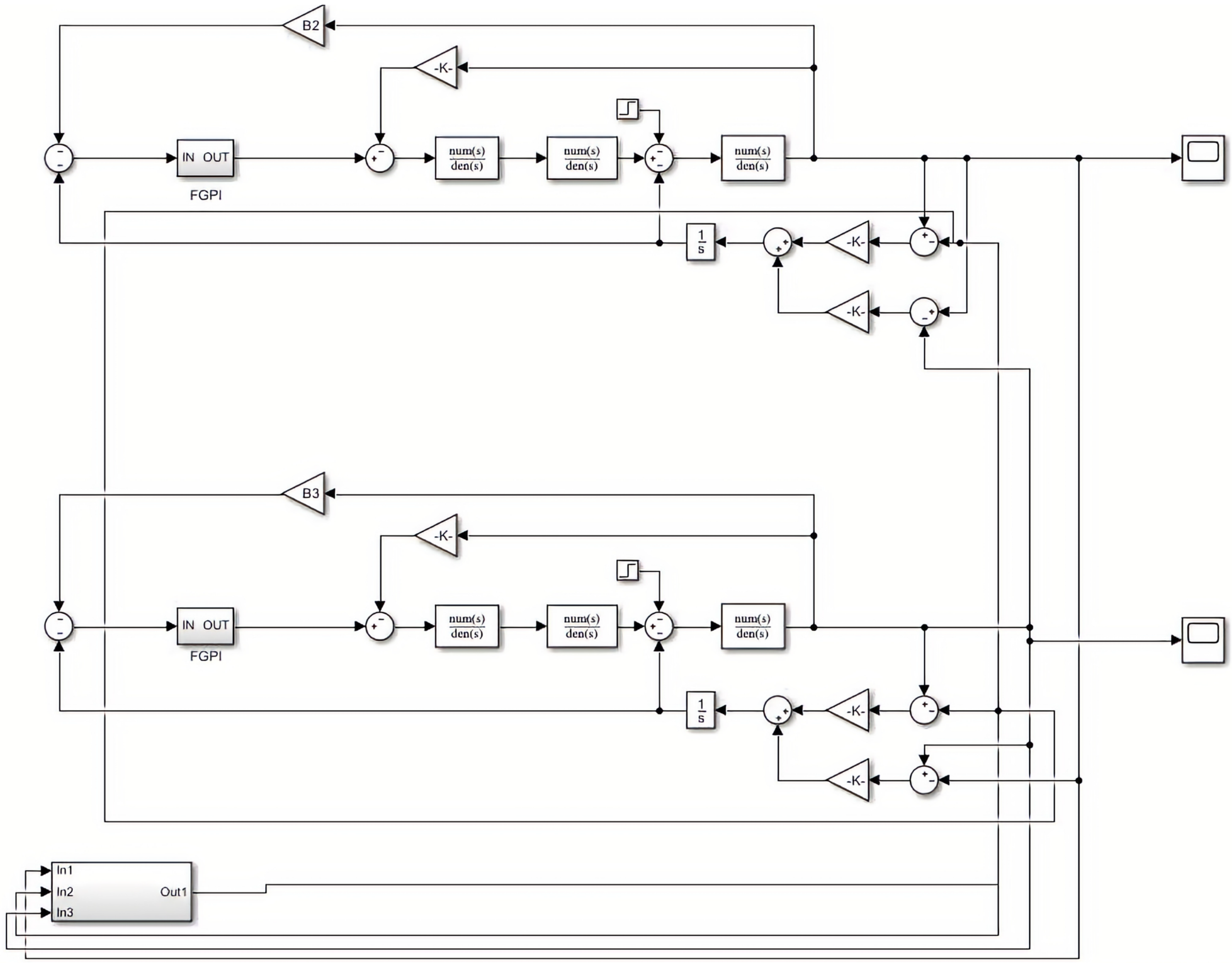

Fig. 9. Simulation of the system using SIMULINK

Fig. 10. Experimental Result

Fig 8 and Fig 9 shows the simulation of the system in the Simulink. The result shows that initially when the gate is opened, the frequency produced fluctuates, so the servomotor adjusts the opening until it stabilizes the frequency. The LFC calculates this degree precisely, so as the water flows and enters the system, the frequency stabilizes producing reliable power that the consumer can use.

The FIS file generated by the MATLAB Fuzzy Logic Toolbox was converted to Arduino C sketch using the program in [16]. The generated Arduino C sketch was then programmed and uploaded to the Arduino Uno.

The results were considered in the deployment following actual testing on Barangay Magsaysay, Atimonan, Quezon. The pico-hydropower system was installed in the mini falls. Table I shows the actual data on the site. It shows that frequency is high when there is no load open. As the load increases, the frequency decreases and the servomotor adjust the opening of the gate so that the water is controlled, and the frequency is stabilized. Rated power of the system is 200W. A safe load must be established to protect the load from damage. There is 20% allowance for safe load. The water flow rate is measured by bucket method. Upon trials for 2 days, the minimum and maximum flow ratewas obtained. It is also noted that flow rate may still vary relying on the accessibility of the water in the site.

TABLE 1
DATA AND RESULT UPON TESTING ON THE SITE

Trial	Load (Light Bulb)	Servomotor (95 degrees = Fully Open)	No. of Load (18W each)	Power Consumed (W)	Frequency (Hz)
1	0	45	0	0	64-65
2	1	60	1	18	59-60
3	2	80	2	36	55-56
4	3	95	3	54	50-51
5	4	95	4	72	45-46
6	5	95	5	90	41-42
7	6	95	6	108	36-37
8	7	95	7	126	33-34
9	8	95	8	144	32-33
10	9	95	9	162	32-33

Rated Power (P_{rated}):	200 W
Total Load Power:	162 W
Safe Load Power:	80% x P_{rated};160W
Minimum Flow Rate:	5.7142857 l/s
Maximum Flow Rate:	9.7560976 l/s
Flow Rate Capacity of Turbine:	35 l/s

Fig 11 and Fig 12 shows the relationship of servomotor opening and the controlled frequency of the system, respectively. Fig 11 shows that as the load increases, the servomotor opening increases so that the frequency will be controlled. On the other hand, Fig 12 shows that as the frequency decreases because of load demands, the servomotor opening increases to let more water flow on the system and sustain the frequency needed.

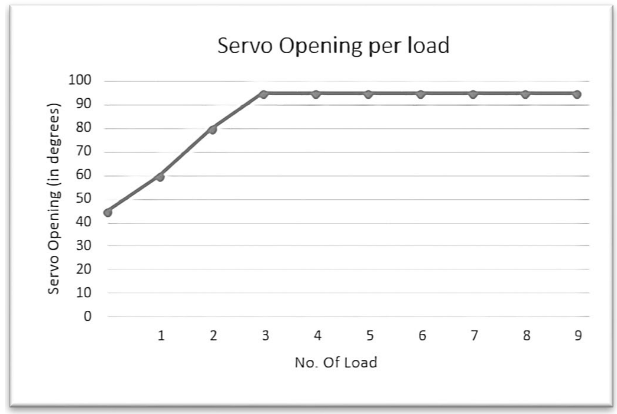

Fig. 11. Graphical Analysis of servomotor opening and number of loads

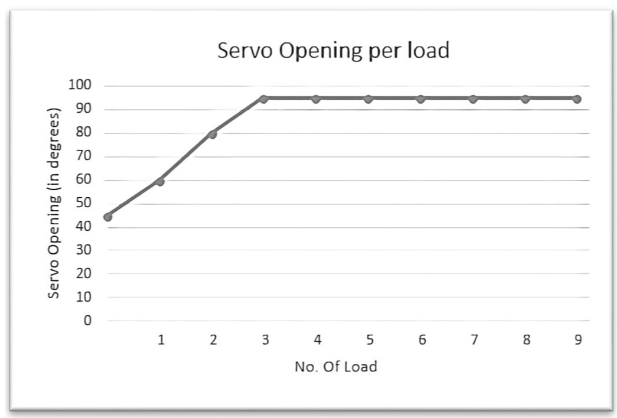

Fig. 12. Graphical Analysis of controlled frequency (Hz) and servomotor opening (degrees)

V. CONCLUSION

The study proved that maintaining the required frequency of 60 Hz within 10% tolerance is necessary. With the use of the servo motor and the frequency controller, the flow of water can be controlled automatically. The generator works perfectly as the water flows continuously. It produces 180-260 Volts AC and can supply electricity on the cottages. The solar panel helps the system on producing electricity and it gives power on the frequency controller. The effectiveness of the generator depends on the flow of water on the river. The system can produce much more electricity if the pressure of water is greater. This project is very efficient because it produces electricity using the water pressure on the river, very eco-friendly and useful to the community of Atimonan, Quezon. With the help of the pico-hydro generator, the households during nighttime now have access to electricity, thus creating a great impact to this province. Thus, it sustained the high pressure of water during rainy seasons. And with proper maintenance, it could work anytime.

Acknowledgement

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