Proceedings of the 2014 Industrial and Systems Engineering Research Conference
Y. Guan and H. Liao, eds.

Mini Hydro-Electric Power Plant with Re-Circulated Water Power Source

Rogelio Cabang Agbanlog, Guangming Chen
Department of Industrial and Systems Engineering
Morgan State University
Baltimore, MD 21251
United States of America

Abstract

This research was conducted to explore the feasibility of designing a Mini-Hydro Electric Power Plant wherein bodies of water such as streams, lakes, and rivers are not available. The above-mentioned bodies of water will not be used as a source of water power for the system. System components shall consist of the following: an elevated water storage tank, a hydraulic turbine coupled to a power generator, a hydraulic ram with a waste-water catching basin, identical air sealed primary and secondary water storage tanks, and a battery bank with AC/DC Inverter. Water needed for turbine operation shall be stored on an elevated water storage tank and shall be piped to the hydraulic turbine which is coupled to a power generator that will be charging a bank of batteries. Emerging water from the hydraulic turbine shall be re-circulated back to the elevated water storage tank through the use of the combined operation of the hydraulic ram and through the water recirculation process used from the modified Heron's siphon principle. If further developed, this technology will be of potential use as a sustainable source of electrical power and energy.

Keywords

Mini Hydro-Electric Plant, Hydraulic Turbine, Hydraulic Ram, ANOVA, Power Generator

1. Introduction

Hydropower has been utilized by humans for thousands of years. It was used to perform work such as grinding of wheat into flour, to saw wood, to generate power for textile mills and manufacturing plants. [1]

Based on the 2013 Key World Energy Statistics released by the International Energy Agency, hydro power utilization is 2.3% of the world's source of primary energy supply. There was a slight increase of 0.5% in fuel shares on the utilization of hydro-electric power worldwide from 1973 to 2011. [2]

This research is primarily aimed for conducting a research in utilizing this type of renewable source of energy, in conjunction with new and emerging technologies, so as to further decrease mankind's dependence on fossil fuels in producing power and electricity.

It is also aimed for combining and utilizing processes in order to conceptually design a mini-hydroelectric power plant that will be environment-friendly and can be constructed and operated without the presence of bodies of water such as lakes, rivers, waterfalls, and streams.

2. Design of the New Mini Hydro-Electric Power Plant

All designs of hydroelectric power facilities have one thing in common: they all require a continuous source of water in order to operate. Large facilities require dams and large water reservoir to maintain a continuous supply of water for driving the hydraulic turbine to produce power. [3, 4]

In this research, the new design eliminates the need for a continuous source of water such as rivers, streams, and falls, and also the need to construct dams to serve as water reservoir to sustain the needed water requirement to operate the plant. [5, 6]

The re-designed hydroelectric power system shall be of a closed process wherein the water supplied to the hydraulic turbine will be re-circulated by means of new discoveries and technologies in water transport and delivery, thereby eliminating the need for a continuous supply of water coming from streams, rivers, waterfalls, and dams.

The main components of the re-designed hydroelectric power system shall be presented and selection of the optimum size of hydraulic turbine capacity will be verified by using Analysis of Variance (ANOVA) for engineering experimental design.

Following the discussion on the main components of the re-designed hydropower system shall be pertinent mathematical formulas and calculations to prove the workability of the new design.

Additional materials shall be presented in order to prove the operational claim of the new design.

The scope of this research is limited to the design of mini hydroelectric power system with main application to small residential dwellings. As this is a new design, the researcher finds it to be practical and more appropriate to design a simple system first for verification of the design principle's workability.

The main components of the new design of mini hydro-electric power system are as follows:

- The Hydraulic Turbine
- The Hydraulic Ram
- The Modified Heron's Fountain Water Re-circulator

2.1 The Hydraulic Turbine

A hydraulic turbine is a mechanism which utilizes the energy from moving water to produce electrical power. Its development started in the 19^{th} century and is widely used for industrial power prior to electrical grids. Figure 1 show a cut-away view of a typical hydraulic turbine coupled to a generator. [7]

As seen on Figure 1, hydraulic turbine (A) operates on a flowing water (point 5) directed on to its blades (point 4) thereby creating a force on the blade to keep the turbine shaft (point 6) spinning. This results to the transformation of water power to mechanical power. The turbine shaft (point 6) is directly coupled to a generator (A) where mechanical energy is transformed to electrical energy.

For the purpose of this research, the type of turbine that will be used throughout this project shall be the Harris Pelton Turbine (Figure 2). This kind of hydraulic turbine is used for low flow, low to high head situations which makes it an ideal component for the conceptual design of this project.

The Harris Pelton Turbine can generate some power with as little as two gallons per minute, and can handle more flow with the accommodation of four half-inch jets. The runner has a 4-inch pitch diameter which can rotate at 1800 revolutions per minute with a minimal pressure of only 32 pounds per square inch.

An Engineering Experimental Design using ANOVA Software was performed to determine the optimum size of Hydro-electric Alternator that will be used for residential application. The experimental design for this testing process consists of two factors: one factor is the feet of head (we tested 25, 50,75,100,200,300, etc.); the other factor is the flow rate gallon per minute (GPM, we tested 3, 6, 10, 15, 20, 30, 50,100, 200 gallon per minute).

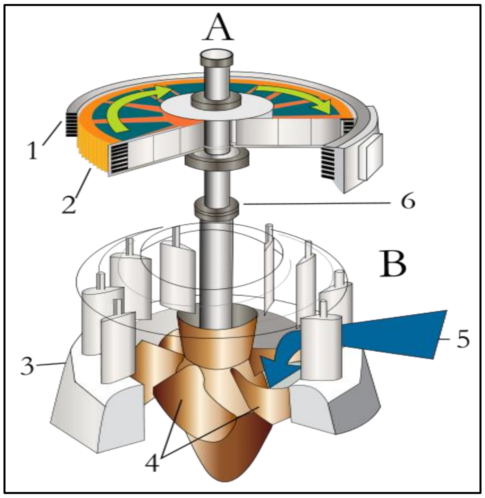

Figure 1: Cut-away View of Hydraulic Turbine and Electrical Generator

A – Generator
B – Turbine
1 – Stator
2 – Rotor
3 – Wicket Gate
4 – Turbine Blade
5 – Water Flow
6 – Turbine Generator Shaft

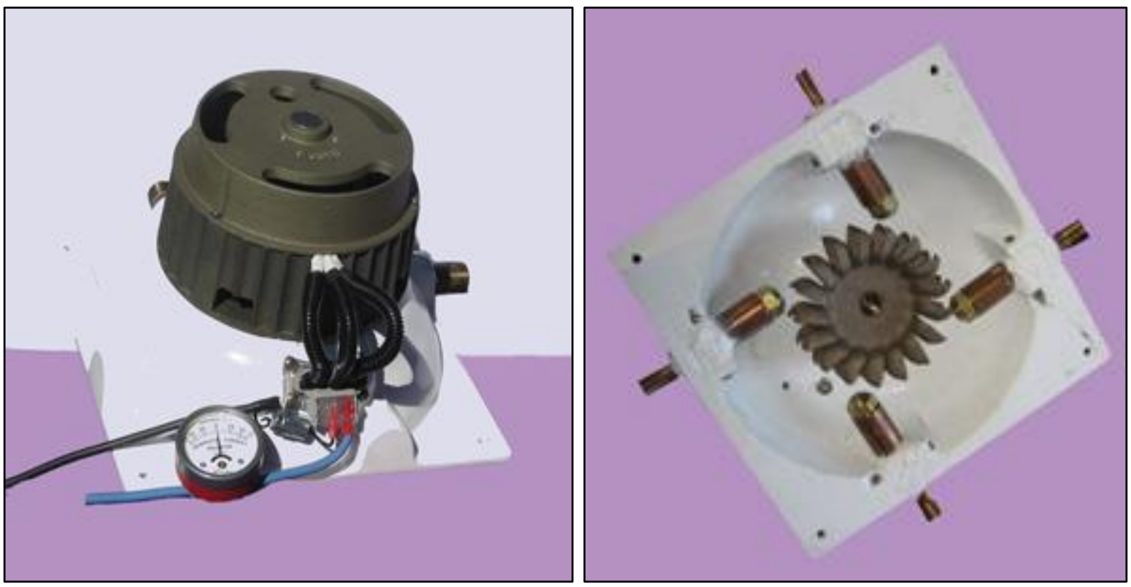

Figure 2: The Harris Pelton Runner

Table 1 gives a summary of the data collection for Harris PM.
Alternator Output for various head versus the gallons of water per minute used.

Table 1 was modified based on the information provided by the present designer of the Harris Hydroelectric PM Alternator, Mr. Dennis Ledbetter, Mechanical Engineer and Machinist of Harris Hydro-Electric System.

Since the test was repeated four times for each level combination of the two factors, Table 2 contains all repeated test results for the four repeated tests with a data range value of ±1% as recommended by Mr. Ledbetter.

Using the ANOVA Minitab Software, we can develop the ANOVA table as in Table 3 which indicates both factors and interaction are significant. Thus, these factors and interaction effects can significantly affect the output power. [8]

	FEET OF NET HEAD					
GPM	**25**	**50**	**75**	**100**	**200**	**300**
3	9	18	25	36	45	80
6	18	20	30	45	130	180
10	20	50	80	105	225	350
15	35	85	115	170	350	520
20	63	120	170	240	480	700
30	100	175	270	360	675	1000
50	150	310	450	620	1100	1500
100	300	560	850	1100	1500	2600
200	596	725	1050	1300	2258	3233

Table 1: Harris Hydroelectric Permanent Magnet Alternator Output (in Watts)

	FEET OF NET HEAD																	
GPM	25			50			75			100			200			300		
3	8.9	9.1	36	18.1	18.1	72	24.9	25.2	100	35.9	36.1	144	45.1	45.1	180	80.7	80.3	320
	9.0	9.0		17.9	17.9		24.9	25		36.2	35.8		44.9	44.9		79.6	79.4	
6	17.9	17.9	72	19.8	20	80	29.9	30.2	120	45.1	45.1	180	131	129.3	520	178.5	180.1	720
	18.1	18.1		20.1	20.1		29.8	30.1		44.9	44.9		129.5	130.2		181.4	180	
10	19.8	20	80	49.8	50	200	80.7	80.3	320	105.2	104.4	420	225.2	227.1	900	349.7	348.6	1400
	20.1	20.1		50	50.2		79.6	79.4		105.2	105.2		223.1	224.6		349.6	352.1	
15	34.8	35.3	140	85.8	84.3	340	115.4	115.5	460	171.4	169.9	680	349.7	348.6	1400	519	518.1	2080
	34.9	35		85.7	84.2		114.8	114.3		168.3	170.4		349.6	352.1		522	520.9	
20	63.6	62.4	252	120.5	119.8	480	171.4	169.9	680	242.3	237.7	960	480.1	481.6	1920	699.8	702	2800
	62.5	63.5		120.4	119.3		168.3	170.4		241.9	238.1		482.7	475.6		704	694.2	
30	100.6	99.7	400	176.4	173.6	700	269.8	268.6	1080	358.1	362.7	1440	672.3	676.8	2700	1004.1	997.6	4000
	99.7	100		174.6	175.4		269.5	272.1		356.7	362.5		674.1	676.8		997.4	1000.9	
50	150.1	150.2	600	308.6	311.6	1240	453.3	451.5	1800	623.7	626.1	2480	1105	1098.5	4400	1496.4	1509.3	6000
	149.8	149.9		311.1	308.7		448.6	446.6		615.4	614.8		1106.6	1089.9		1502.3	1492	
100	298.1	301.2	1200	565	559.8	2240	851	852.4	3400	1105	1098.5	4400	1496.4	1509.3	6000	2259.8	2251.3	9032
	300.8	299.9		560.6	554.6		849.2	847.4		1106.6	1089.9		1502.3	1492		2259.9	2261	
200	598.9	594.5	2384	719.2	728.4	2900	1048.8	1052	4200	1297.7	1297.4	5200	2259.8	2251.3	9032	3230.5	3238.5	12932
	592.9	597.7		727.2	725.2		1050.2	1049		1305	1299.9		2259.9	2261		3240	3223	

Table 2: Harris Hydroelectric Permanent Magnet Alternator Output with Linear Approximation
±1% Output Range as per Manufacturer's Recommendation (in Watts)

Figure 3 is the Graphical Plot of the ANOVA Analysis, which will provide the reader the visual interpretation of the result of Minitab Calculations.

2.2 The Hydraulic Ram Pump

The Hydraulic Ram Pump is one of the two most important components of the Mini Hydro-Electric Power System which will initiate the water re-circulation process in the system together with the modified Heron Siphon.

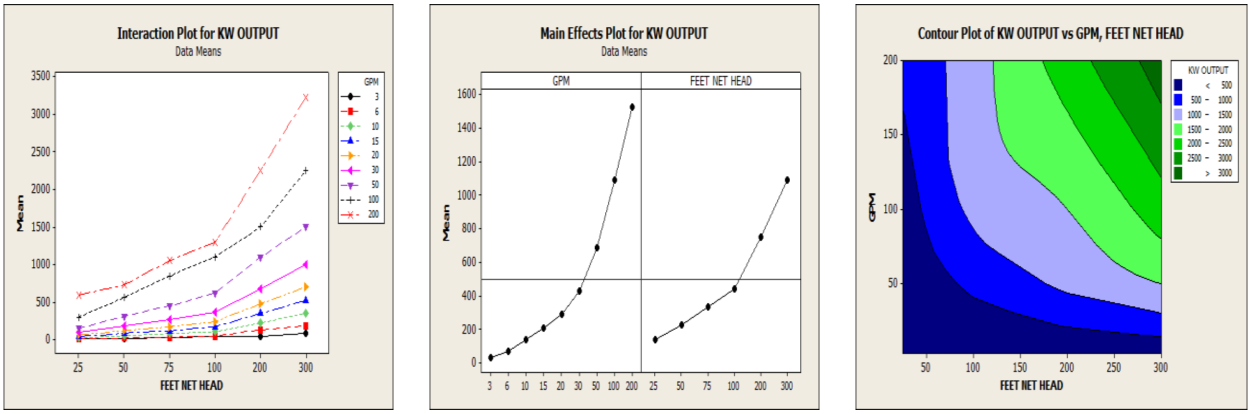

Figure 3: Graphical Plot of ANOVA Analysis

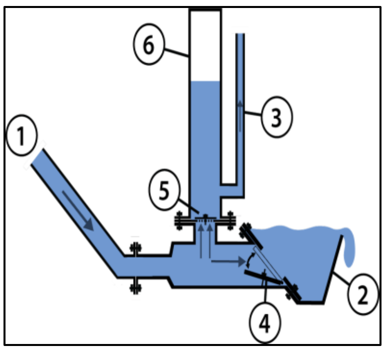

Figure 4: Components of a Hydraulic Ram Pump

Analysis of Variance for KW OUTPUT, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
GPM	8	50500084	50500084	6312511	655560.41	0.000
FEET NET HEAD	5	23145691	23145691	4629138	480740.53	0.000
GPM*FEET NET HEAD	40	17733941	17733941	443349	46042.18	0.000
Error	162	1560	1560	10		
Total	215	91381276				

Table 3: Analysis of Variance for Watt Output

These are the two primary mechanisms of the system which will totally eliminate the need of a dam and the continuous flow of water from rivers, streams, and dams, as it will be used to re-circulate the water in the system that will drive the hydraulic turbine to produce mechanical power.

The basic components of a hydraulic ram pump are shown in Figure 4. There are only two moving parts on a hydraulic ram pump; the waste valve (4), and the delivery check valve (5). Other than these moving parts, the rest are stationary parts. Other components include a drive pipe (1) which supplies water from an elevated source, the delivery pipe (3) which delivers a portion of the water coming from the drive pipe to an elevation higher than the source. [9]

The sequence of operation of the hydraulic ram pump is very simple and very straightforward. On the initial stage of operation, the waste valve (4) is open and the delivery valve (5) is closed. Since the supply water is coming from an elevated source, due to gravitational force, water from the drive pipe (1) builds up kinetic energy with increasing drag force closing the waste valve (4). As soon as the waste valve (4) closes, water flowing from the supply pipe gains enough momentum to cause a water hammer which raises the pressure in the pump and eventually opens the delivery check valve (5). At this instant, water is forced to flow into the delivery pipe (3) due to the compressed air inside the pressure vessel (6). Since water is being forced to flow to a destination that is higher in elevation, the water flow will soon slows down due to the compressed air inside the pressure vessel (6), and then the flow reverses. At this stage, the delivery check valve (5) closes. All this time water flows to the delivery pipe (3). Then, water pressure in the lower portion of the pump decreases opening
the waste valve (4) allowing the water to flow through the drive pipe again. Once water builds it momentum again, the waste valve (4) closes again, the delivery check valves opens, and the cycle starts again.

Figure 5: AIDFI Hydraulic Ram

Figure 5 is a commercially manufactured hydraulic ram pump from the Philippines.

The equations below constitute an ideal system for a hydraulic ram pump:

For Ideal System:

$$qh = QH \tag{1}$$

where:

q - output flow of the system (gpm)
h - output height (feet)
Q - drive flow of the system (gpm)
H - drive head (feet)

Taking the efficiency (ή) of the pump into consideration, equation (1) becomes:

$$ή = qh \; / \; QH \tag{2}$$

$$\text{Delivery Flow } (q) = QHή \, / \, h \tag{3}$$

In order to maintain a good delivery flow, the pump efficiency should be high, the drive flow should be large enough to maintain the desired delivered flow, and the delivery head should not be many times larger than the drive head. For a 100% efficient hydraulic ram pump, the pump can only deliver 20% of the drive flow as it can only lift a fraction of the flow that drives it. The ration between deliver head to drive head (h/H) is also within a typical range between 5 to 25. This means that for a one foot drive head and a drive flow of 10 gallons, there can only be 2 gallons of water that can be delivered to a maximum height of 25 ft.

A typical hydraulic ramp pump has an efficiency range of 50% to 80%. For standard calculations, if the efficiency is not known, it is best to assume it to be between 50% to 60% to calculate the expected delivery flow. Efficiency of poorly maintained pump with very long drive pipe and a very high ratio of drive head to delivery head can go as low as 40%. Manufacturers usually provide guidance to users to operate the pump under normal conditions in order to maintain the optimum efficiency design for pump operation.

The hydraulic ram system power (P) can be calculated as follows:

$$P = 9.81 \, (q/60) \; h \tag{4}$$

Where:

P - the power in Watts
q - the delivery flow in liters/minute
h - the delivery head in meters
9.81 - acceleration due to gravity

It is necessary to know the hydraulic power for the ram pump in order to know the power consumption equivalent compared to using an electrical powered pump. This will serve as a reference guide for future design of system using a hydraulic ram.

2.2 Modified Heron's Siphon (Fountain)

Heron's Fountain (siphon) was invented by Heron, a 1st century AD inventor, mathematician and physicist. He was also known as Hero of Alexandria.

Since the original set-up of the Heron's Siphon has water flow limitations and does not have the perpetual capability of circulating water in the fountain, a modified design has been made in order to improve the design and make the water delivery and circulation perpetual.

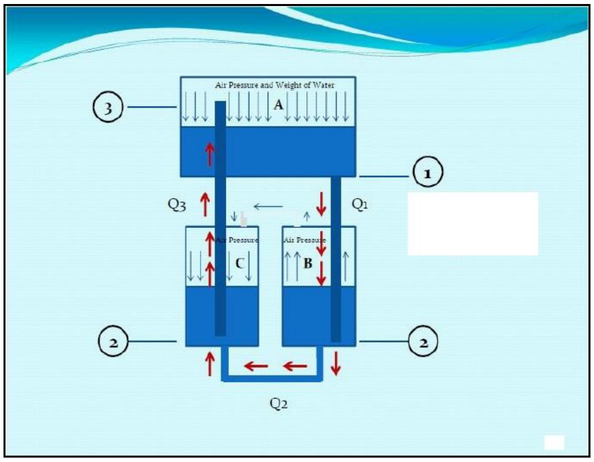

Figure 6: Modified Heron's Principle

Figure 6 shows the modified set-up of the Heron's Siphon. The set-up works the same way as with the original set. However, few modifications have been made in order to make the flow of water perpetual.

As shown on Figure 13, water in container A flows to container B by means of gravity thru a pipe connection from the bottom of container A extending up to nearly the bottom of container B. Container B which is actually the air supply container for the system is connected to another air-tight sealed container C thru a bottom water pipe and a top air pipe connecting both containers B and C hydraulically and pneumatically.

On the initial step, both containers B and C are half-filled with water. As water flows from container A to container B, the amount of water for both container B and C tends to equalize. As water is being filled in container B, air is being displaced to container C. Since water level in container C is also rising due to the flow of water going to container B, due to pressure differential between container C and the pipe connected to container A, water then flows upward thru that pipe and it is delivered back to container A. In order to maintain the continuous flow of water within the system, it is important that all containers shall all be air tight. Any leak on any of the containers will result in reduced air pressure to lift the water from container C to container A.

The continuous water circulation within the modified Heron's fountain can be best explained using hydrostatic calculations.

At point 2 (reference point), hydrostatically, the pressures are equal. Taking this into consideration, the following equations can be derived: [10-12]

$$P_2 = PA + \rho w g h_{1-2} \quad (5)$$

$$P_2 = PB + \rho w g h_{3-2} \quad (6)$$

$$PB = PC \quad (7)$$

Equate (5) and (6):

$$PA + \rho w g h_{1-2} = PB + \rho w g h_{3-2} \quad (8)$$

$$PA - PB = \rho w g h_{3-2} - \rho w g h_{1-2} \quad (9)$$

Where:

- P_2 = pressure at point 2
- PA = pressure at water storage tank A
- PB = pressure at water storage tank B
- PC = pressure at water storage tank C
- ρw = density of water
- h_{1-2} = difference in elevation between point 1 and point 2
- h_{3-2} = difference in elevation between point 3 and point 2

The difference in pressure between container A and container C is the driving factor for the perpetual flow of water within the system. Container A maybe sealed or it may be not. However, the advantage of having container A sealed is that as water begins to circulate within the system, there will be a pressure build up in container A which will result to increase water flow between container A and container B.

On the succeeding pages, it will be shown how the principles presented herein were consolidated in order to arrive to a concept that will be a breakthrough on the design of modern hydroelectric power systems.

3. Discussions

On the preceding section of this report, the basic components of the new designed mini hydroelectric power system were presented.

In this section, discussions will be made on the consolidation of these components in order to arrive to a new design that will be a breakthrough in the design of modern hydroelectrical power system.

3.1 The New Design
Figure 7 shows a layout of the new design for a close system mini hydroelectric power system with re-circulated water supply circuit.

As you can see on the layout, the components that were discussed earlier were consolidated in order to maintain the continuous flow of water into the system.
The new system consist of an elevated storage tank A, a hydraulic turbine coupled to a generator, the hydraulic ram, and two air tight storage tanks (Tank A and Tank B) which operates on the principle of the modified Heron's Siphon.

3.2 Principles of Operation
Referring to Figure 7, water from the elevated storage tank, by gravity, flows through a connecting pipe leading to the hydraulic turbine. Depending on the net head H, the kinetic energy (hydro power) stored on the flowing water shall be converted by the hydraulic turbine into mechanical power which in turn shall be converted into electrical power by means of the power generator.

From the hydraulic turbine, water flows to the hydraulic ram by means of a connecting pipe. Portion of the water shall be pumped by the hydraulic ram going back to the elevated storage tank A to be re-circulated back to the hydraulic turbine. The remaining quantity of water passing the hydraulic ram shall be disposed through the waste water catchment and shall be piped to storage Tank B. Storage Tanks B and C are of the same elevation and are air tight. As the water level rises in Tank B, air is displaced to Storage Tank C. Since Tank B and Tank C are of the same elevation and any rise of water in Tank B shall also result to a rise of water level in Tank C, and the air displaced from Tank B is also piped to Tank C, this will result to a flow of water thru the pipe in Storage Tank C. This water pipe is connected in a location between the hydraulic turbine and the hydraulic ram. By means of pressure differential as discussed in the Methodology section of this report, a continuous flow of water will result due to this principle.

Due to this continuous flow of water within the system, an adequate water can be supplied to the hydraulic turbine that is coupled to a generator. The generator charges a bank of batteries which is the primary storage of energy of the system. The bank batteries is connected to a dc-ac power converter to raise the voltage to 120V which is the common voltage being used for residential application.

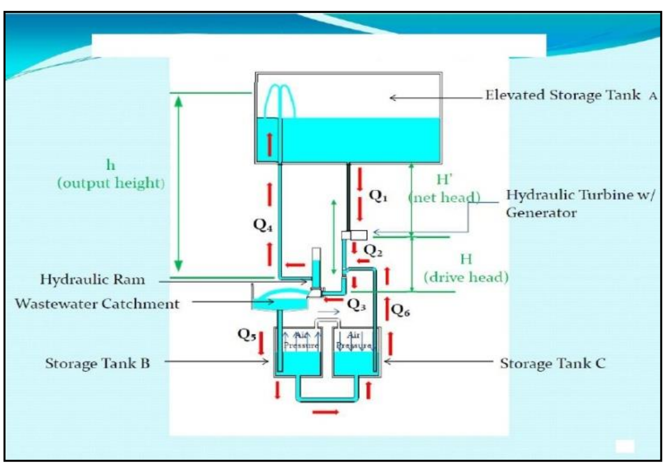

Figure 7: Model Principle of Operation

3.3 System Water Flow Balance
Referring back to Figure 7, assume that the system has no leak and there are no losses in the amount of water re-circulating in the system.

The following water flow balance was derived:

$$Q_1 = Q_2 = Q_4 \quad (10)$$

$$Q_3 = Q_2 + Q_6 \quad (11)$$

$$Q_4 = 0.2Q_3 \quad (12)$$

$$Q_5 = 0.8Q_3 \quad (13)$$

$$Q_6 = Q_5 \quad (14)$$

Where:

Q - the volume of water at any point within the System

Be noted that the quantity of water flowing back to the elevated storage tank A is only 0.2 of Q_3. Since this is the case, the quantity of water that needs to be delivered back to the elevated storage tank A should be equal to the quantity of water needed to pass through the hydraulic turbine for power generation, to maintain a balance flow of water within the system.

4. Results and Deliverables

4.1. Equipment Selection

Based on the result of the ANOVA Analysis that was conducted, the following selection can be made for a single unit residential application:

Flow (in gallons per minute):	50 gpm
Net Head (in feet):	25 ft.
Hydraulic Turbine Output (Watts):	150W continuous
Therefore, the power generated in 24 hours of operation shall be:	
Power Generated (24 hours):	150W x 24 hrs. = 3600 W-h

Due to the fact that the amount of water flow (gpm) and the Net Head has an effect on the output capability of the Harris Hydroelectric PM Alternator as shown on the result of the Analysis of Variance for KW output on Table 3, any combination of flow and head can be selected in Table 1. However, the researcher made a reasonable judgment on selecting the above combination due to the fact that the project is only for residential application.

4.2 Residential Set-up

Figure 8 is the set up fitted for this application. As you may see on the layout, the hydro-generator output is connected to a bank of battery system with a corresponding voltage regulator. The battery bank is connected to a DC – AC Inverter to convert voltage from 12V to 120 volts. 120V is the usual residential voltage supply here in the United States.

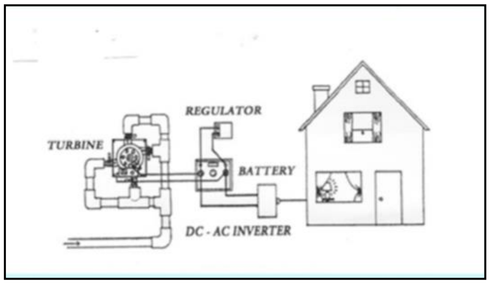

Figure 8: Residential System Set-up

4.3 Battery System Sizing Estimator

Table 4 is a summary of a typical electrical system requirement for a residential dwelling. The wattage is the standard wattage for each system load. Estimated hours of use is the average use for each system load based on daily usage.

Total daily watt-hour required is the total power needed to sustain the operation of the system load.

A three day contingency power supply allowance was included on the calculations in the event that the system fails. In the calculations, three days of down time duration was assumed.

For a 12V 105A-H capacity for each battery, eight (8) battery units will be required for this application.

Based on the total watts of the entire system load, a 2000W power inverter is needed to convert 12V to 120V. A higher rating inverter is favorable in case additional loads will be used.

It is also highly recommended that a charge controller be installed in order to prevent the overcharging of the batteries. Use of a charge controller will result to a prolonged battery life.

Table 4: Battery System Sizing

SYSTEM LOAD	Watts	Estimated Hrs. of Use (daily)	WattHours
Refrigerator (4 to 5 cu. ft.)	80	9	720
Television (25 to 27 inch LCD)	120	4	480
Microwave (1000 watts)	1000	30 mins.	500
House Lights (add wattage of lights in all rooms)	200	4	800
Computer System (DeskTop LCD)	110	3	330
Miscellaneous Items (Extra Watts for items not included)	100	2	200
TOTAL DAILY WATT-HOUR REQUIRED:			3030
WATT-HOUR REQUIRED FOR 3 DAYS (3030W X 3 DAYS):			9090
12V BATTERY BANK SIZE IN A-H (9090W / 12V) :			757.5
(12V @ 105 A-H) NUMBER OF BATTERIES REQUIRED (757.5 A-H / 105 A-H):			8
MIN. POWER INVERTER RATING REQUIRED (TOTAL WATTS = 1610W) :			2000W
ADD CHARGE CONTROLLER TO PREVENT OVERCHARGING OF BATTERIES			

5. Conclusions and Future Development

Based on the result of the study that was conducted, the following were concluded:

- The System can be constructed on locations where there are no means of constructing a dam for water reservoir, or no available streams or waterfalls is present.
- All components and materials for construction are readily available in the market.
- There are no complicated processes or procedures that is involve for the system to work.
- Compared to other renewable source of power such as solar and wind power, hydroelectric power system provides a constant power output at all times.

Based on the power output outcome on the electrical calculations, the project is highly feasible.

The design concept for this project can be further developed and can be a start of a newly modernized way of utilizing and constructing hydropower generation system that is more environmentally friendly because of its compactness.

Further research on the main components of the system, specifically the hydraulic ram, the hydraulic turbine, and the modified Heron's Siphon principle will be a major step in the development of a much more efficient and much more reliable hydro power systems in the future.

Acknowledgement

First of all, I would like to thank our Almighty God for giving me guidance and inspirations to complete this Research Project.

I also would like to thank Dr. Corey Dickens for sharing with me the conceptual design of this project.

To my adviser Dr. Guangming Chen who has been very supportive and understanding.

To Dr. Seong Lee who had given me the initial path in conducting research projects.

To all my other professors Dr. Tridip Bardhan, Dr. Bheem Kattel, and Dr. John Evans who un-selfishly shared with me their knowledge, experience, and expertise that made me a better engineer.

And to all the other faculties and staffs of the Industrial and System Engineering Department at Morgan State University.

References

[1] History of Hydropower, U.S. Department of Energy
[2] 2013 Key World Energy Statistics, page 6, International Energy Agency
[3] Hydroelectric Power, Water Encyclopedia
[4] www.electricityforum.com/hydroelectricity.html
[5] Douglas T. Broomhall P, Orr C. (2007), Run-of-the-River Hydropower in BC: A Citizen's Guide to Understanding Approvals, Impacts, and Sustainability of Independent Power Projects, Watershed Watch.
[6] www.en.wikipedia.org/wiki/Hydroelectric_power
[7] Davis, Scott, Micro Hydro Clean Power from Water, New Society Publishers, 2003, p. 58.
[8] Douglas C. Montgomery, Design and Analysis of Experiments, 8th Edition, John Wiley & Sons Inc., Chapter 5, Factorial Design, p. 183.
[9] T.D. Jeffrey, T.H. Thomas, A.V. Smith, P.B. Glover, and P.D. Fountain, Hydraulic Ram Pumps, Intermediate Technology Publications Ltd.
[10] Michael R. Lindenburg, P.E., FE Review Manual 2nd Edition, Professional Publications Inc., p. 23-2.
[11] Michael J. Moran, Howard N. Shapiro, Fundamentals of Engineering Thermodynamics 5th Edition, John Wiley & Sons Inc., p. 13-15.
[12] J. Kenneth Salisbury, Kent's Mechanical Engineer's Handbook 12th Edition, Power Volume, John Wiley & Sons Inc., p. 5-09 to 5-16