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RECYCLED MICRO HYDROPOWER GENERATION USING HYDRAULIC RAM PUMP (HYDRAM)

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ABSTRACT

A micro-hydropower plant capable of generating about 15 kW from falling water for a housing estate or personal property that is not served by the electrical grid is presented. Three surface tanks, one underground tank, a turbine generator set and one pump with associated pipes constitute the micro hydropower plant. A hydraulic ram pump is used to increase the head of the falling water. The flow rates of water out of tanks and pumping rate of water into a tank are designed to operate optimally. In order that the flow rates are maintained constant, controlled actuator is designed to activate the pump as the need arises while flow regulator is fitted in another tank to keep the flow rate at a predetermined value. The underground tank is made to collect rain water and is capable of meeting the water need of the micro hydropower plant for the off rain periods. The micro hydropower plant can easily be adapted for remote environment since most of the components including the ram pump can be fabricated locally.

KEYWORDS: Micro-Hydropower, Hydraulic Ram Pump, Flow Rate, Recycled

INTRODUCTION

Micro-hydropower systems are receiving increasing attention from owners of housing estates and others who have property that is not served by the electrical grid. Micro-hydropower systems are relatively small power sources that are appropriate in most cases for individual users or groups of users who are independent of the electricity supply grid. A micro-hydropower system is generally classified as having a generating capacity of less than 100 kW [1]. The systems offer a stable, inflation-proof, economical and renewable source of electricity that uses proven and available technologies. Advancements over the years have demonstrated that water power can produce many times more power and energy than several other sources for the same capital investment.

Many micro-hydropower systems operate “run of river,” which means that neither a large dam or water storage reservoir is built nor is land flooded. Only a fraction of the available stream flow at a given time is used to generate power, and this has little environmental impact. The amount of energy that can be captured depends on the amount of water flowing per second (the flow rate) and the height from which the water falls (the head). Hydropower comes from converting potential energy in flowing or falling water by means of a water wheel or through a turbine into useful mechanical power. This power is converted into electricity using an electric generator or is used directly to run milling machines [1], [2].

Diesel and gasoline generators are currently cheaper to buy, but the increasing cost of fuel oil and maintenance has made them expensive to operate. There is also the effect of their long-term environmental impact. Small and micro-hydropower installations have, historically, been cheap to run but expensive to build. This is now changing, with smaller, lighter and more efficient higher-speed turbine equipment, the lower cost of electronic speed- and load-control systems, and inexpensive plastic penstock pipes.

Conventional reversible small hydropower also known as pumped hydro storage is a large energy storage technique widely used in power systems. Water is pumped from a lower reservoir into an upper reservoir, using excess electricity generated by the hydropower plant during off-peak hours or at any other times when demand is reduced. During the peak load times or at other times when extra electricity is needed, extra electricity is generated from water stored in the upper reservoir as it is released back to the lower reservoir via a turbine generating electricity in order to meet the energy demand. Reversible small hydropower scheme comprises an upper reservoir, pump, turbine, motor, generator, penstock, and a lower reservoir.

In this paper, a steady recycled pumped storage micro hydropower scheme employing hydraulic ram (hydram) pump is proposed. A hydram or impulse pump is an automatic pumping device which uses the energy of falling water to lift a lesser amount of water to a higher elevation than the source without using electricity or any other power source [3], [4]. With a continuous flow of water, a hydram operates automatically and continuously with no other external energy source. It is a structurally simple unit consisting of two moving parts: the waste valve and delivery (check) valve. The unit also consist an air chamber and an air (snifter) valve. The operation of a hydram is intermittent due to the cyclic opening and closing of the waste and delivery valves. The closure of the waste valve creates a high pressure rise in the drive pipe. An air chamber is necessary to prevent these high intermittent pumped flows into a continuous stream of flow. The air valve allows air into the hydram to replace the air absorbed by the water due to the high pressures and mixing in the air chamber.

During each pumping cycle only a very small amount of water is pumped. However, with cycle after cycle continuing over 24 hours, a significant amount of water can be lifted. While the ram pump is operating, the water flowing out the waste valve splashes onto the pump house and is considered waste water. Although waste water is not delivered by the ram pump, it is the energy of this water that pumps the water which is delivered. The waste water from the ram pump utilized in this design is collected and recycled back to create a potential energy for another cycle of operation. Figure 1 shows the setup of the micro-hydropower plant. The setup comprises four water tanks: closed tank1 (CT1), closed tank2 (CT2), surface reservoir tank (SRT) and underground reservoir tank (URT), one hydraulic ram pump, one pumping machine, and a turbine-generator inside a power.

RECYCLED MICRO HYDROPOWER SYSTEM

The primary interest in this paper is to develop micro hydropower system that utilizes the energy in a falling water to generate steady electric power. The falling water is from an overhead tank located remotely from a river or stream or any other natural flowing water. This system is feasible and realizable if constant flow and head are maintained in the CT1 for the turbine generator set. CT1 supplies water through the penstock with a definite flow rate and head to the turbine generator set in order to generate constant electrical power. CT2 supplies water through the drive pipe also with a definite flow rate to the ram pump. The ram pump in turn pumps water to CT1 through the delivery pipe with a definite pumping rate equal to or greater than the flow rate of water out of CT1. The import of the ram pump is to pump water from CT2 to a higher CT1 in order to gain higher head. For easy identification, let us denote the flow rate of water out of CT2 as Q1, the flow rate of water out of SRT as Q2, the pumping rate of water into CT1 as Q3 and the flow rate of water out of CT1 as Q4. Optimal operation is attained by setting Q1 equal to Q2 and Q3 equal to Q4. To achieve constant flow rate for Q2 since the water level in SRT can vary depending on certain conditions, a flow rate regulator is fitted into the orifice of the flow pipe linking SRT and CT2. The flow rate regulator utilizes a diaphragm which changes shape with inlet pressure changes, thus maintaining a constant flow rate.

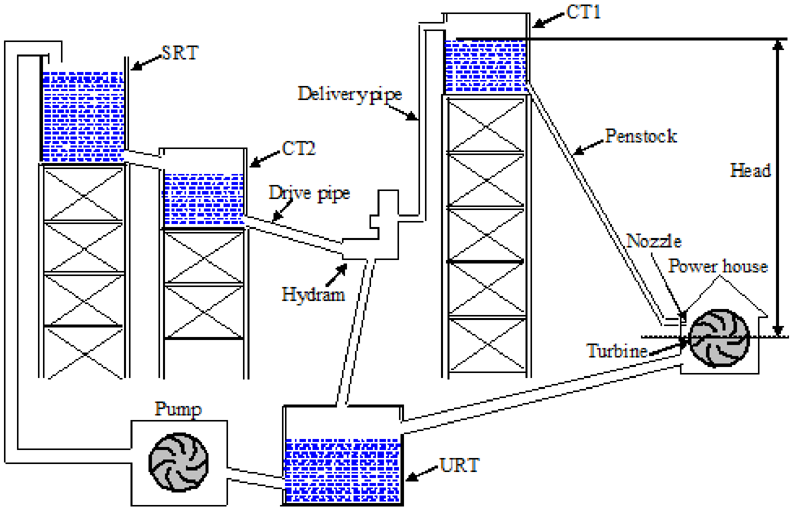


Figure 1: Setup of the Micro-Hydropower Plant Using Hydrams

Located in the inner surface of SRT are two sensors: the lower sensor and the upper sensor. The lower sensor has the task of turning the pump ON when the water level drops below it or it is dry. The upper sensor has the task of turning the pump OFF when the water level reaches it or it is wet. Each time the pump is turned ON water is pumped from the larger URT onto SRT. The water in URT is made up of water from the turbine, waste water from the ram pump and rain water collected during the rainy season. Allowance is provided in the SRT to also accommodate rain water.

The amount of hydraulic power available from a hydropower system is directly related to the flow rate, head and the force of gravity as [5]

$$P_h = Q * H * g * \rho \tag{1}$$

The electrical power is obtained as:

$$P_e = P_h * \eta = Q * H * g * \rho * \eta \tag{2}$$

where, P_h and P_e are the theoretical hydraulic and electrical power outputs respectively in W, Q is usable flow rate in m^3/s, H is net head in m, g is gravitational constant ($9.81 m/s^2$), η is efficiency factor (turbine and generator, 0.5 – 0.7), and ρ is density of water ($1.0\ kg/m^3$). Once Q and H in equations (1) and (2) are kept constant at their developed values relative to design constraints, the system will be capable of supplying constant plant power.

Design and Sizing

The amount of power derivable from the plant structure depends on the head H and the usable flow rate Q4. To this end, a steady supply and sustained volume of water in the CT1 must be maintained. These requirements are made possible by setting a constant pumping rate Q3 for the ram pump. The constant pumping rate of the ram pump is in turn made possible by setting a definite flow rate Q1 for the water flowing into the ram pump. The flow rate Q2 is dependent on Q1 so that Q1 sets the value for all other Q's.

- **Determination of Flow Rates of Water**

The level of water in a tank and the size of a penstock pipe are paramount to the determination of the usable flow rate of the water through the penstock. The generic equation for determining the flow rate may be described as the product of the cross-sectional area A, of the orifice of the penstock multiplied by the average flow velocity v, as:

$$Q = v * A \quad (3)$$

The average flow velocity is obtained as:

$$v = \sqrt{2 * g * h} \quad (4)$$

where g is the gravitational acceleration and h is the height difference between the top of the orifice and the surface of the water in the tank as indicated in Figure 2. Combining equations (3) and (4) yields:

$$Q = \sqrt{2 * g * h} * \frac{\pi * D^2}{4} \quad (5)$$

where D is the diameter of the orifice of the penstock.

From equation (5) it is obvious that the usable flow rate of water through the penstock depends on the differential height h, and the diameter of the orifice of the penstock D. The choice of size and type of penstock depends on several factors but basically, the trade-off between head loss and capital cost.

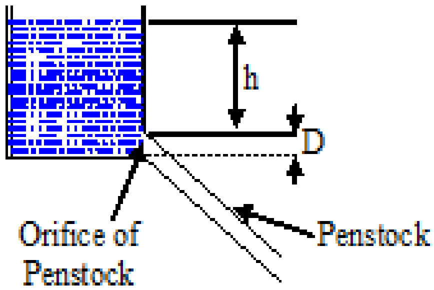


Figure 2: Diagram Showing Height Difference h, and Diameter D, of Orifice of Penstock

In this special design however, calculation of the usable flow rate is guided by the possibility of maintaining steady water level and hence constant h in the affected tanks.

- **Net Head**

The net head H is the difference between the gross head and the losses due to friction and turbulence in the penstock piping. Gross head is the vertical distance between the top of the penstock that conveys the water under pressure and the point where the water discharges from the turbine as indicated in Figure 3.

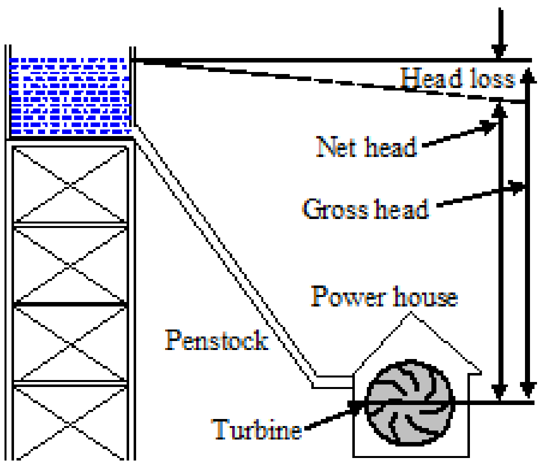


Figure 3: Diagram Showing Head Loss, Net Head and Gross Head

Head loss due to friction in the penstock pipe depends principally on the velocity of the water, the roughness of the pipe wall and the length and diameter of the pipe. The losses decrease substantially with increased pipe diameter. Conversely, pipe costs increase steeply with diameter. Therefore, a compromise between cost and performance is required. The design philosophy is to first identify available pipe options, select a target head loss of 5 to 10 percent or less of the gross head, and keep the length as short as possible.

In this design therefore, a net head is selected as:

$$NH = GH - h_{Lf} \tag{6}$$

where NH is the net head and GH is the gross head.

- **Turbine**

The choice of turbine depends mainly on the head and the design flow for the proposed micro hydropower installation. The selection also depends on the desired running speed of the generator. Pelton and Turgo turbines are the most commonly used impulse-type turbines in micro-hydropower systems. These turbines are simple to manufacture, are relatively cheap and have good efficiency and reliability. In this design, Turgo turbine which is characterized for its operation under medium head range (30m – 100m) is selected. Owing to the need for high pressure for it operate properly, use is made of a small nozzle or adjustable nozzle.

- **Generator**

As the heart of the micro electrical power system, generators convert the mechanical (rotational) energy produced by the turbine to electrical energy. A 4-pole synchronous generator of 1800-rpm is the most commonly used generators for micro hydro turbines.

Depending on the size of the generator, full-load efficiencies of synchronous generators vary from 75 to 90 percent. In order to match the speed of the generator to the low speed of the turbine, a "V" or wedge belts and pulleys speed increaser is adopted.

- **Hydraulic Ram Pump**

A hydraulic ram or impulse pump is an automatic pumping device which uses the energy of falling water to lift a lesser amount of water to a higher elevation than the source without using electricity or any other power source. It is designed to deliver the desired pumping flow rate for a given elevation lift. The range of available flow rates and elevation lifts is related to the flow quantity and velocity from the water source through the drive pipe. Figure 4 is its pictorial view while Figure 5 is a schematic view showing how it operates.

Water flows from the source through the drive pipe **A** and escapes through the waste valve **B** until it builds enough pressure to suddenly close the waste valve. Water then surges through the interior discharge valve **C** into the air chamber **D**, compressing air trapped in the chamber. When the pressurized water reaches equilibrium with the trapped air, it rebounds, causing the discharge valve **C** to close. Pressurized water then escapes from the air chamber through a check valve and up the delivery pipe **E** to its destination. The closing of the discharge valve **C** causes a slight vacuum, allowing the waste valve **B** to open again, initiating a new cycle [4]. The cycle repeats between 20 and 100 times per minute, depending upon the flow rate.

There are only two moving parts the waste valve and discharge valve, thus there is little to wear out. Hydraulic rams are relatively economical to purchase and install. For effective operation the ram must at least be 0.5m below the water source and water must be needed at a level higher than the source.

The mathematical relationship for pumping flow rate is based upon the flow rate through the drive pipe, the vertical fall from the source through the drive pipe, and the vertical elevation lift from the pump to the point of use. These variables are illustrated in Figure 6.

Figure 4: Pictorial View of Hydraulic Ram Pump

The pumping flow rate is calculated as:

$$Q = 1440 * \frac{S * F * E}{L} \tag{7}$$

where

Q is the amount delivered in gallons per day (gpd); S is the source flow rate through the drive pipe in gallons per minute (gpm); F is the fall or height of the source above the ram in meters; E is the efficiency of the ram (for commercial models use 0.6); L is the vertical elevation lift from the pump to the point of use above the ram in meters (m).

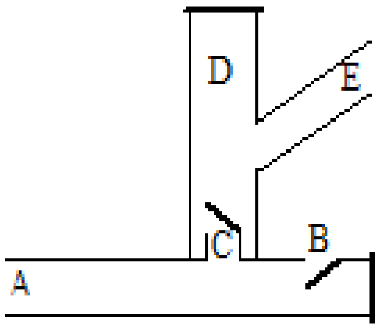


Figure 5: Schematic View of Hydraulic Ram Pump

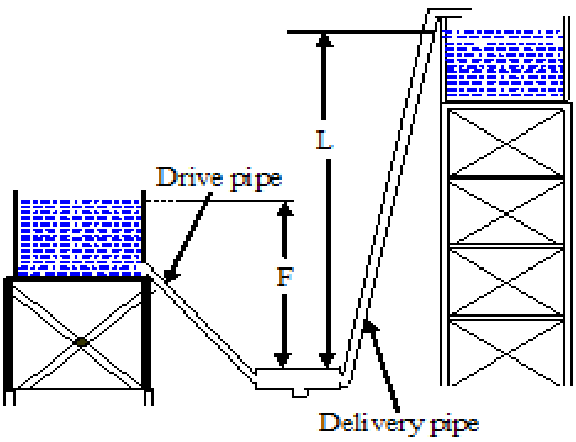


Figure 6: System Layout for Calculation of Pumping Rate

Calculations for Pumping and Flow Rates

- **Flow Rate of Water Out of CT2 'Q1'**

In order that enough pumping rate of water from the hydraulic ram pump into CT1 is obtained, higher flow rate of water from CT2 into the ram pump is demanded. By this requirement, a differential height of 6m and the diameter of orifice of the drive pipe of 20cm respectively are selected. From equation (5), the flow rate is determined to be 0.3407 m^3/s or 5400.205 gpm.

- **Flow Rate of Water Out of SRT 'Q2'**

It has been stated that for optimal operation to be attained Q1 should be made equal to Q2. A flow rate regulator is fitted into the orifice of the flow pipe linking SRT and CT2. The flow rate regulator utilizes a diaphragm which changes shape with inlet pressure changes. The flow rate is by this maintained at 0.3407 m/s or 5400.2065 gpm. By making Q2 equal to Q1, the differential height h in CT2 is kept constant to maintain Q2 constant.

- **Pumping Rate of Water Into CT1 'Q3'**

The ram pump is required to pump water into CT1 at a rate higher than water flows out of it. A fall height and elevation height of 4m and 10m respectively are selected. For the 5400.205 gallons per minute flow rate of water from CT2 and efficiency of 0.6 for the ram pump, the pumping rate of water by the pump into CT1 by equation (7) is 1866326.4 gpd or 0.081769 m^3/s.

- **Usable Flow Rate of Water Out of CT1 'Q4'**

The usable flow rate of water Q4 from CT1 through the penstock to the turbine multiplied by the net head H gives approximately the required electrical power from the turbine generator set. From equation (5) the only feasible variable that can be altered so that Q4 becomes equal to Q3 is the differential height h. This requirement sets the differential height at 5.5302m with a diameter of orifice of the penstock of 10cm. The usable flow is 1866326.4 gpd or 0.081769 m^3/s.

If we assume a 10% friction head loss for a 30m gross head chosen in this design, the net head becomes 27m.

For an assumed turbine and generator set efficiency of 0.7 and net head of 27m, the theoretical electrical power output of the generator is 15.15 kW. A 15 kW synchronous generator may be purchased for the micro hydropower system.

Action of Water Pump

It is anticipated that not all the water that left the power house and the ram pump can be recycled back into CT2 for another cycle of operation as some may be wasted through some natural means. The effects of these wastages may not be felt since provision is made for the underground reservoir tank to accommodate rainwater and water from any other source. A call to duty for the water pump is conditioned by the level of water in SRT. During the rainy days this call may not be frequent. If adequate provision for the collection of rain water in the URT is made, the URT is capable of meeting the water need of the micro hydropower plant for the off rain periods.

The summary of the obtained designed parameters are tabulated in Table 1.

Table 1: Summary of Obtained Designed Parameters

	H(m)	D(m)	F(m)	L(m)	Q	
					m^3/s	gpm
Q1	6	0.2	-	-	0.3407	5400
Q2	-	-	-	-	0.3407	5400

Table 1: Contd.,

Q3	-	-	4	10	0.0818	1296
Q4	5.53	0.1	-	-	0.0818	1296

WATER PUMP CONTROL

The water pump control is equipped with two transducers: the lower sensor and the upper sensor. The lower sensor has the task of turning the pump ON when the water level in SRT drops below the sensor or the sensor is dry. The upper sensor has the task of turning the pump OFF when the water level reaches the sensor or the sensor is wet.

The control circuit is designed to be digital. There will be an actuator to activate the pump and an indicator in the form of a flashing LED. Let us assign the following variables: A for lower sensor, B for the upper sensor, C for pump and indicator ON, D for pump and indicator to turn ON or stay ON. The operations of the variables are tabulated as shown Table 2. The truth table representation of the control operations is shown in Table 3 while the simplified logic circuit is drawn as shown in Figure 7 after the application of the Boolean laws. The practical electronic control circuit can easily be realized with few discrete and integrated circuit IC components and an actuator.

Table 2: Operations of the Control Variables

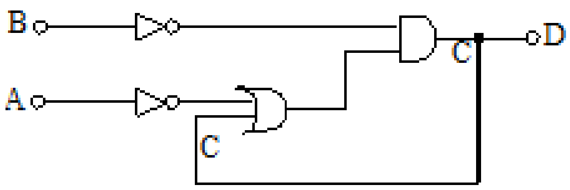
Lower Sensor	**Upper Sensor**	**Pump and Indicator ON**	**Pump and Indicator to Turn ON or Remain ON**
A	**B**	**C**	**D**
Dry	Dry	No	Yes
Wet	Dry	Yes	Yes
Wet	Wet	Yes	No
Wet	Wet	No	No
Wet	Dry	No	No
Dry	Dry	No	Yes
Dry	Dry	Yes	Yes

Table 3: The Truth Table

A	B	C	D	
0	0	0	1	$D = \overline{A}\,\overline{B}\,\overline{C}$
1	0	1	1	$D = A\overline{B}C$
1	1	1	0	
1	1	0	0	
1	0	0	0	
0	0	0	1	$D = \overline{A}\,\overline{B}\,\overline{C}$
0	0	1	1	$D = \overline{A}\,\overline{B}C$

Sum-of-products Boolean equation:

$$D = (\overline{A}\,\overline{B}\,\overline{C}) + (A\overline{B}C) + (\overline{A}\,\overline{B}C)$$



$$D = \overline{B}(\overline{A} + C)$$

Figure 7: Simplified Logic Circuit of the Pump Operation

CONCLUSIONS

A micro-hydropower plant capable of generating about 15 kW from falling water for a housing estate or personal property that is not served by the electrical grid is presented. The falling water is artificially created by use of hydraulic ram pump to increase the head which when multiplied by the generated usable flow rate gives the approximate electrical power output. Optimal procedure is adopted in the design of the flow rates Q1, Q2 and Q4 and pumping rate Q3 of water out of the tanks and into the tank respectively to ensure steady and constant plant power. In order that the flow rates are maintained constant, controlled actuator is located in one of the tanks to activate the pump as the need arises while flow regulator is fitted in another tank to keep the flow rate at a predetermined value. A simplified digital design is adopted for the pump controller while practical electronic control circuit can easily be realized with few discrete and integrated circuit IC components and an actuator.

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