International Journal of Agricultural Sciences
Volume **12** | Issue 1 | January, 2016 | 60-64 ■ e ISSN-0976-5670
DOI:10.15740/HAS/IJAS/12.1/60-64
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RESEARCH PAPER

Design and development of pelton wheel for pico-hydro power generation unit

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Abstract : The smallest hydroelectric systems, with power generation below 5 kW is termed as pico-hydro power. The Konkan region of the Maharashtra state, receives a very heavy rainfall, to the tune of 3000 to 4500 mm from June to September. Due to high intensity, duration and frequency of the rainfall, the electricity transmission lines get damaged due to falling of trees or bad weather. The rainwater which falls on the roof tops of the houses has a great pico-scale hydroelectric potential. This rainwater, which falls on roof tops possesses the potential energy. If this water is made to fall on a turbine with a high velocity, electricity can be generated. Houses in Konkan region, having an average height of 8 m, or more (ground floor, first floor and roof) and assuming a roof water collection area of about 10 × 10 m; by calculation, it is observed that, there is a potential to generate about 50 to 60 W of hydro power. This power can lit four to five LED lights of 10 W capacities each.

Key Words : : Design, Development, Pelton wheel, Pico-hydro power, Generation unit

View Point Article : Aware, Seema V., Aware, Vijay V., Kushal, Samel and Pachbhai, Puja (2016). Design and development of pelton wheel for pico-hydro power generation unit. *Internat. J. agric. Sci.,* **12** (1) : 60-64.

Article History : Received : 10.11.2015; **Revised :** 27.11.2015; **Accepted :** 09.12.2015

INTRODUCTION

Pico-hydro power is a term used to describe the smallest hydroelectric systems, covering power generation under 5 kW (Kapoor, 2013). Depending on its size, a pico-hydro power system may provide a small, remote community with adequate electricity to power light bulbs, radios and televisions, among other appliances. Pico-hydro technology has become an economic source of power, even in some of the world's poorest and most inaccessible places. It is also a versatile power source. Mechanical power can be utilized with some designs. Recent studies by the World Bank Energy Unit found that, the pico-hydro power yielded the lowest generating costs amongst off-grid energy options. Pico-hydro is recognized as a viable option to electrify remote areas, considering economic, environmental and social perspectives. Almost all over the countries of the world, there are numerous pico-hydro sites particularly in the hilly areas. Pico-hydro power is meant only for a family or a household and not for a village or community. It is also termed as "Family hydro power". Such very small scale hydro power generation has a large potential, but is still left unexplored due to lack of awareness and high cost of turbines, generators and low wattage lamps.

Water source having adequate height and flow rates have feasibility of developing pico-hydro power project (Kapoor, 2013). Sabarinathan and Thulasidharan (2013) designed and developed a pico-hydro generation system using kinetic energy of water flowing through irrigation

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pipes. Chauhan and Yadav (2014) designed and developed a pico-hydro system using house hold water supply; a head of 6 m and flow of 0.285 lps resulted 8.4 W at 1500 rpm considering 50 per cent efficiency. Rain water harvested and was made to fall on a Pelton turbine from 60 m height at the rate of 0.01 cum/s lead to generation of 701 kWh (Martin and Sharma, 2014).

Potential pico-hydropower in Konkan :

The Konkan region of the Maharashtra state, receives a very heavy rainfall, in the range of 3000 to 4500 mm from June to September. Due to high intensity, duration and frequency of the rainfall, the electricity transmission lines get damaged due to falling of trees or bad weather. Thus, the supply of electricity is hampered. Also, there are power cuts in the Konkan region, due to insufficiency of electricity. The rain water which falls on the roof tops of the houses have a great pico-scale hydro electric potential. Unfortunately, the rain water falling on roof tops eventually ends up in the runoff stream. This rain water, which falls on roof tops possesses the potential energy. If this water is made to fall on a turbine with a high velocity, electricity can be generated. Houses in Konkan region, having an average height of 8 m, or more (ground floor, first floor and roof) and assuming a roof water collection area of about 10 × 10 m; by calculation, it is observed that, there is a potential to generate about 50 to 60 W of hydro power. This power can lit four to five LED lights of 10 W capacity each. As the height and the roof area of the building increases, the hydro power generated also increases and hence, more low wattage electrical appliances can be utilized. If during the rainy season, power cut occurs, then such a small scale hydro power generator will keep the house lit.

Pelton turbines :

The pelton turbine is an impulse hydro turbine developed in 1889 by an American engineer Lester Allan Pelton. Pelton turbine is a tangential flow impulse turbine, which operates under high head of water and requires comparatively less quantity of water. Martin and Sharma (2014) opined that, for domestic power generation through roof top rain water harvesting, Pelton wheel is the most economical. Water is conveyed in penstocks from head race to the turbine in power house. The runner of the pelton turbine consists of buckets having double hemispherical cups fitted on its periphery. The cups have a semi-ellipsoidal shape. The rear of the bucket is designed such that the water leaving the bucket should not interfere with the passage of water to the preceding bucket.

The jet strikes these cups at the central dividing edge of the front edge. The central dividing edge is also called as splitter. The water jet strikes edge of the splitter symmetrically and equally distributed into the two halves of hemispherical bucket. The inlet angle of the jet is therefore between 1° and 3º. Theoretically if the buckets are exactly hemispherical it would deflect the jet through 180°. Then the relative velocity of the jet leaving the bucket would be opposite in direction to the relative velocity of the jet entering. This cannot be achieved practically because the jet leaving the bucket then strikes the back of the succeeding bucket and hence, overall efficiency would decrease. Therefore, in practice the angular deflection of the jet in the bucket is limited to about 165° or 170°, and the bucket is slightly smaller than a hemisphere in size. Water, at high head, flows through the penstock and at the end of penstock, one or more nozzles are fitted to convert all the available energy of water into kinetic energy. The amount of water which discharges from the nozzle is regulated by a needle valve provided inside the nozzle. One or more water jets can be provided with the pelton turbine depending on the requirement.

MATERIAL AND METHODS

This point deals with the materials and methodology adopted for studying the development of pico-hydro electric power generation unit.

Design of pelton turbine :

The pelton turbine was designed for high efficiency and at a pico-hydro power scale (Nasir, 2013).

Annual average rainfall in Konkan region is assumed as 3500 mm.

Assuming 50 days of rainfall in the entire monsoon season, Daily rainfall = 70 mm = 0.07 m

Assuming a roof of size 10 × 10 m, which will collect rainwater in 2 hours,

$$\text{Discharge of water } Q = \frac{10 \times 10 \times 0.07}{2 \times 6060} m^3/s = 0.971/s \approx 11/s$$

Assuming a head H of 9 m,

Water horse power = Q (1/s) x H (m) x 9.81=88.29 W

Assuming a 60 per cent hydropower unit efficiency,

Output horse power = water horse power × efficiency

$$= 88.29 \times 0.6 = 52.97 \text{ W} \approx 53 \text{ W}$$

Assuming a co-efficient of velocity Cv= 0.98,

Absolute velocity of jet v (m/s) = $Cv \times \sqrt{2gh}$

$$= 0.98 \times \sqrt{2 \times 9.81 \times 9}$$

$$= 13.022 \text{ m/s} \approx 13 \text{ m/s}$$

Assuming speed ratio = 0.5,

Absolute velocity of runner = speed ratio × Absolute velocity of jet

$$= 0.5 \times 13.022$$

Absolute velocity of runner = 6.51 m/s

Velocity of runner = $\pi \times D \times N/60$ where,

D = runner diameter (m) and N = runner rotations in rpm

Putting v = 6.51 m/s and N = 300 rpm, we get, Diameter of runner D = 41.5 cm = 415 mm 18

Single jet pelton turbine is assumed.

Hence, according to the discharge continuity equation,

$$Q = \pi \frac{\pi}{4} x\, d^2 \, x\, v,$$

where d = diameter of jet. Putting values of Q = 0.001 m^3/s and v = 13.022 m/s, we get,

$$d = 9.89 \text{ mm} \approx 10 \text{ mm.}$$

$$\text{Jet ratio} = \frac{D}{d} = \frac{415}{10} = 41.5$$

No. of buckets = 0.5 × jet ratio + 15 = 0.5 × 41.5 + 15 = 35.75 ≈ 36 buckets

Bucket width = 5 × jet diameter = 5 × 10 = 50 mm

Bucket depth = 1.2 × 10 = 12 mm.

Development of the turbine :

A 10 m long and 60 mm diameter UPVC (Un-plasticized Poly Vinyl Chloride) pipe was sheared perpendicularly into 36 cylindrical pieces, each having 65 mm length, using a hacksaw blade. The pieces were sheared at a plane, 5 mm apart from the diametrical line of the cylinder, so that two un-identical (large and small) cups were obtained. This process was done by a shaping machine. A v-groove was made at one end of the cup, using a hand abrasive cutter. The internal angle of the v-groove was 55° while the length of the base of v-groove was 50 mm. The stainless steel sheet was cut into 36 pieces using a sheet cutter. The dimension of each piece was 70 mm × 35 mm. Two holes were drilled into each stainless steel piece, exactly at the centre line, parallel to the length (70 mm) of the piece at a distance of 15 mm from extreme ends. The sheet pieces were then subjected to the deforming force of a mechanical press, such that, a splitter shape was formed (the sheet was pressed parallel to the breadth (35 mm) of the piece at 3 points: 2 drilled points and the midpoint on the length). The stainless steel splitters were mounted on the concave side of the cups and were fixed by stainless steel screws. The cups were attached one after the other, on the periphery of the wooden runner, with the help of stainless steel screws (2 screws per cup). This was carried out by using a protractor and dividing the circular face of the runner into 36 equal parts (each part subtending 10° at the center). A 32 mm hole was drilled into the wooden runner at its centre, by using a lathe machine. Using lathe machine, hub and shaft were manufactured out of mild steel. The hub shaft was made to penetrate the hole made on the centre of the runner, using a mechanical press. The hub flange was attached to the wooden runner using stainless steel screws, so that, the runner and the hub would behave as a single rotating unit. A key hole was drilled into the turbine shaft, in order to fix it inside the hub shaft. The turbine shaft was made to penetrate the hub shaft. Both the shafts were aligned, such that, the drilled holes on the hub shaft and the turbine shaft would match. A long bolt was made to penetrate the key passage. The bolt was tightened with a nut and it was ensured that, the runner, the hub and the turbine shaft were rotating as a single unit. The two ends of the shaft were mounted inside the bearing bushes of the pedestal bearings. Two P-205 pedestal bearings, having 25 mm internal diameter of bearing bush were used. The turbine was painted with red oxide and paint, in order to protect it from water. The developed pelton turbine is shown in Plate A.

Plate A : Pelton turbine

Assembling of the frame :

Using an abrasive cutter (rotating at 5000 rpm), a mild steel angle was cut into several appropriate pieces. The final frame was made by welding 4 angles into a rectangular framework and supporting it with 4 smaller angles at all the vertexes. All the fixations were done by A.C. welding (440 V supply, 90 V transformer and varying current). Angles of smaller dimensions were welded together, in order to support gearbox, D.C. generator, multimeter and nozzle of the penstock pipe. The entire frame was coated with layers of red oxide and paint, in order to protect it from rusting.

Assembling of the machine :

The two pedestal bearings holding the turbine shaft (along with the entire turbine) were placed on the main rectangular frame. The bearings were fixed on the frame, by drilling holes in the frame and fixing with nuts and bolts. The turbine was adjusted on the center of the frame for stability and the screws on the bearing bush were tightened in order to prevent play. The gearbox, D.C. generator and the multimeter were mounted on the frame and were fixed by nuts and bolts. The turbine shaft was coupled to the input shaft of the gearbox by using a cotter pin. The output shaft of the gearbox was coupled to the motor shaft using a coupler. The positive and negative wires of the D.C. generator were attached to the positive and negative wires of the multimeter, respectively.

Assembling of the penstock pipe :

The 3 m and 50 mm diameter HDPE pipe was attached to the main water supply, with the help of a 63 mm × 50 mm reducer. The empty was attached to the HDPE pipe on the other end. The bushing was attached to the empty and the hose nipple was attached to the bushing. The hose nipple was fixed on the frame by a nut and bolt arrangement, so that the line of jet could be varied. The diameter of hose nipple (nozzle diameter) was 20 mm. The complete assembly of developed Pico hydro power generator is shown in Plate B.

Plate B : Pico-hydro power generation unit

Testing of developed pico- hydroelectric power generation unit :

The nozzle arrangement at the bottom of the penstock pipe is aligned properly. It is ensured that all the connections on the penstock pipe are watertight. The electrical wiring between motor and multimeter is checked. A 11 W load bulb is fixed into the socket present on the electric board. All the rotating parts are lubricated. The flow is initiated by opening a flow control valve. Water rushes through the penstock pipe, exits from the nozzle and hits the turbine. Using a bucket, measuring cylinder and a stop watch, a 1 l/s flow is adjusted. This was done by diverting the flow from the nozzle into a 24 liter bucket and finding out the time required for filling the bucket. If a 24 liter capacity bucket gets filled in 24 seconds, then the flow becomes 1 l/s. Once the flow was adjusted, the water was allowed to hit the turbine again. It was ensured, that the line of jet was tangential to the turbine and was passing through the midpoint of the buckets.Using a non-contact tachometer, the maximum rotations of the motor shaft and the turbine were recorded in rpm. The maximum readings of the ammeter and the voltmeter were also recorded. Power generated was calculated by multiplying values of the ammeter readings and voltmeter readings. The tachometer, ammeter and voltmeter readings were taken at the same time, after every 10 seconds. This was done 10 times, in order to get 10 readings. The flow was ceased by closing the flow control valve.

RESULTS AND DISCUSSION

The generator unit was successfully developed. The turbine was made up of a wooden runner disc, along with 36 plastic buckets mounted on its curved periphery. Stainless steel splitters were fixed inside each bucket. A hub and shaft penetrated the turbine at its center. The shaft was supported by 2 pedestal bearings on a frame. The shaft of the turbine was coupled to the gearbox of a milk separator. The output worm of the gearbox was coupled to a brushless D.C. generator. The generator was electrically connected to an ammeter and a voltmeter. The water from a water source was made to fall on the turbine, through a penstock pipe. A nozzle arrangement was made at the bottom of the penstock pipe. Water jet with high velocity exited the nozzle and was incident on the buckets of the turbine. Due to the impinging action of water, the turbine rotated. This motion was transferred to the generator via the gearbox. Hence the generator shaft rotated and generated power, which was measured by a multimeter, consisting of an ammeter and a voltmeter. A non-contact tachometer recorded the rotations of the turbine shaft and the motor shaft.

The tachometer, ammeter and voltmeter readings were taken at the same time, after every 10 seconds. This was done 10 times, in order to get 10 readings. It was observed that the turbine rotated at a flow of 1 l/s and a head of 9 m. The average power generated was 13.9 W. There were minute fluctuations in the power generated.

Conclusion:

The pico hydroelectric power generation unit was developed, in accordance with the design for a flow of 1 l/s and a head of 9 m.

The turbine rotated for a flow rate of 1 l/s under head of 9 m. Average power generated was 13.9 W.

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