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Full Length Research Paper

Evaluation of the energy recovery potential at City of Masvingo waterworks using micro-hydro-electric generator

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The potential of implementing energy recovery in the water supply network of the city of Masvingo is investigated. Data from the city's department of engineering was analysed to determine the critical parameters for a hydro-generator. Determinations of the head, maximal discharge and penstock diameter were made. With a maximal discharge of 289 l/s and a gross head of 66 m, an estimated energy recovery potential of 168 kW was possible. This is an amount of power sufficient to power all the operations at town house where a 75 kW diesel generator serves as a standby power source. The annual energy recoverable is estimated to exceed 700 000 kWh which is equivalent to more than US$70 000 at the prevailing electricity tariffs in the country. It was noted that the water delivery was limited to only 12 h a day, hence a standalone generator may not be suitable but implementing a peaking generator integrated into the mains is recommended.

Key words: Energy recovery; micro-hydro generator; City of Masvingo water works.

INTRODUCTION

The demand for energy surpasses production, leaving a deficit in many countries in Sub-Saharan Africa. In particular, Zimbabwe is facing a critical power shortage against an increasing demand. To reduce this deficit, different strategies can be adopted. These may include expanding the generation capacity, implementing energy saving strategies or better still energy recovery. Energy recovery can be implemented in different scenarios such in refrigeration and air conditioning systems, water supply networks, and sewerage treatment plants, desalination plants and in irrigation systems (Aline and Vincent, 2010).

This study seeks to explore the potential of energy recovery in the water supply network of the City of Masvingo by implementing a micro hydro electric generator. The city of Masvingo is located in the Southern part of Zimbabwe and is home to population of 89 000 people (Central Statistical Office, 2014). Drinking water is pumped from Lake Mutirikwi which is located to the south of the city into reservoirs on the hilltop on the south west peripherals of the city before it is discharged into the supply network.

A micro hydro electric generator could be set up to utilise the energy of the water before it is discharged into the network (Aline and Vincent, 2010; Vineesh and Immanuel, 2012; Arun and Prawin, 2013). However this should be done as a secondary benefit without affecting the quality of the water delivery system (Aline and Vincent, 2010; Arun and Prawin, 2013). On the other hand, a turbine integrated into existing infrastructure could add value by acting as a pressure reducing valve which regulates the maximum pressure in the pipe network and save unnecessary burst pipes (Aline and Vincent, 2010; European Small Hydropower Association, 2004). This in particular is a common problem for the lowlying suburban of Rujeko in the city.

Basics of micro hydro power generation

Falling water releases potential energy which can be harnessed for electricity generation (Theophilus, 2010). A turbine integrated into the water fall is used to extract this energy and drive a generator for electricity production. The available energy depends on the height of the water fall as well as the water flow rate at the site. This can be estimated theoretically as (Aline and Vincent, 2010; Theophilus, 2010; Lucy et al., 2012):

$$\mathrm{P} = \rho g h Q \varepsilon \qquad \text{...(1)}$$

where P is the power in watts, ρ is the density of water, g is the acceleration of gravity, h is the height of the water fall, Q is the water flow rate and ε is the generator efficiency.

The annual energy yield of a site will dependent on the duration which the generator is operated. This is defined by the capacity factor which is defined as the actual energy generated in a year expressed as a percentage of the possible energy should the generator be operated continuously (Theophilus, 2010).

Classification of hydro electric power

A hydro power plant is classified according to its installed capacity. However, there are different classification schemes used to classify small hydro power plants and these vary according to location and region. A typical classification scheme for small hydro power plants is given in Table 1 (European Small Hydropower Association, 2004; Theophilus, 2010).

Micro hydropower in a supply network

In a water supply network, a micro hydropower generator can be implemented by integrating a turbine in the discharge system. It utilises the head of the reservoir to drive the turbine as illustrated in Figure 1. The turbine should usually be located where pressure reducing valves are required to control the discharge pressure to desirable levels. This allows the utilisation of the energy which would otherwise be dissipated in the process. The energy generated could be used on site to reduce the energy bill or integrated into the national grid at a price (Theophilus, 2010).

It should also be noted that the inclusion of such a turbine should be done without compromising the primary goal of supplying quality water to the consumers (European Small Hydropower Association, 2004). Bypass valves should be provided to allow the continuous delivery of water in the event of the turbine being stopped for mechanical failure (European Small Hydropower Association, 2004).

Table 1. Classification of hydro electric power.

Type	Installed capacity (kW)
Micro-hydro	upto 100 kW
Mini-hydro	101 kW to 2000 kW
Small hydro	20011 kW to 25 000 kW

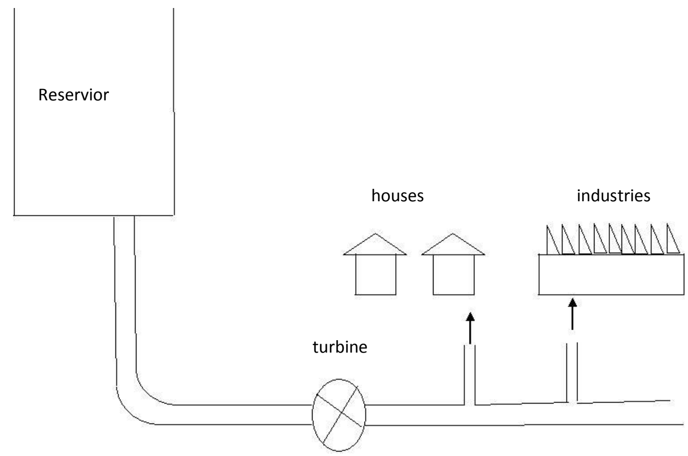

Figure 1. Integrating a micro-hydro generator in a water supply network.

There are two types of turbines used in water distribution networks. These are the Pelton turbine and the Francis turbine. The choice of turbine is guided by the available head in the network. Pelton turbines are preferred for networks operating at low head while the Francis turbine is suitable for networks operating at high pressure (Theophilus, 2010).

METHODOLOGY

The electrical energy generation capacity, P_e of a micro hydro generator is estimated using the equation (Aline and Vincent, 2010; Thophilus, 2010):

$$P_e = \rho \times Q \times \Delta Z \times g \times \eta_c \eta_t \eta_e \eta_{tr} \, (W) \quad \text{..................(2)}$$

Where ρ is the specific weight of water in kg/m^3

Q is the maximal discharge in m^3/s

g is the acceleration due to gravity

ΔZ is the gross head

η_c is the penstock efficiency $\geq 90\%$

η_t turbine efficiency $89\% \leq \eta_t \leq 94\%$

η_e is the generator efficiency $\geq 92\%$

η_{tr} is the transformer efficiency $\geq 97\%$

Data to be used for calculations would be obtained from the city engineer's department. This includes the maximal discharge computed as an average and the size of the delivery pipe. The gross head would be determined from GPS measurements of altitude at designated points and the head loss due to penstock diameter will also be determined. This will be based on the guide given in Table 2 (Vineesh and Immanuel, 2012).

The penstock efficiency would be determined from the size of the delivery pipe while the other parameters which are specific to the adopted design for implementation would only be used as a guide. An attempt would be made to quantify the annual energy output at the proposed site and determine a monetary value of the energy using prevailing electricity tariffs.

RESULTS AND DISCUSSION

The gross head

The gross head = (altitude of reservoir) – (altitude at base of hill)

=(1138 – 1072)m = 66m

The gross head in the network is found to be 66 m which falls within the range 30 to 100 m and hence it can be classified as a medium head scheme [esha]

The penstock diameter

This was provided by the City engineer's department as 600 mm.

The discharge

Daily water supply =12.5 mega litres
Discharge period = 12 h a day.

Thus the average discharge rate can be calculated as:

$$Q = \frac{\text{daily water supply}}{\text{discharge period}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$= \frac{12500000}{12 \times 60 \times 60} \, l/s$$

$=289 l/s$

The discharge of 12.5 Ml over a period of 12 h a day is a result of the limited capacity at pumping station. The reservoir has a total storage capacity of 35 Ml but is never filled to capacity due to the limited pumping capacity. This, thus, greatly reduces the energy potential of the system by reducing the capacity factor of any installation.

Table 2. Head loss due to penstock diameter.

Diameter of penstock (mm)	Head loss/100m (m)
300	40.05
325	27.51
350	19.31
400	10.26

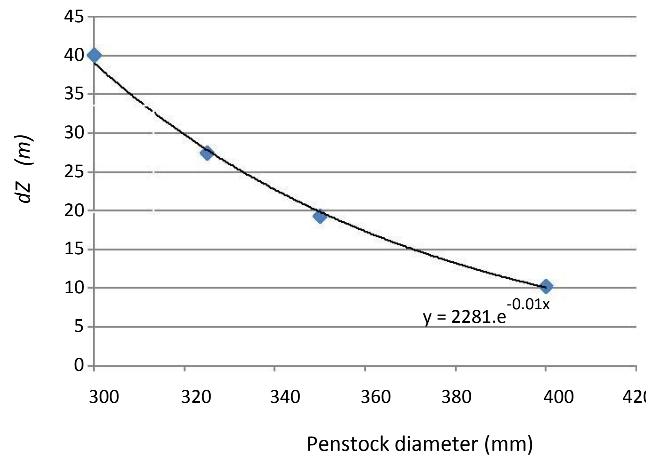

Figure 2. Head loss against penstock diameter.

Head loss (dZ)

Head loss is estimated by extrapolation using the guideline of Table 2. By plotting a graph (Figure 2) of penstock diameter against the head loss and apply regression analysis to obtain a suitable equation is used to calculate the appropriate head loss. Using the regression equation with a penstock diameter of 600 mm gives a head loss of 0.51 m per 100 m. This result shows that the head loss can be ignored for the 600 mm diameter penstock.

Estimated power potential

This is calculated from equation (2) using the values given in Table 3. The estimated output power potential for City of Masvingo Water Supply network is found to be:

$$\begin{aligned} P_e &= 1000 \times 0.289 \times 66 \times 9.81 \times 0.9 W \\ &= 168404 W \\ &= 168.4 \text{ kW} \end{aligned}$$

This is a significant amount of power given that the energy requirements at town house are met by a standby generator with a capacity of 75 kVA during electricity

Table 3. Parameters for calculating the output power potential.

Parameter	Value
ρ density of water(kg/m^3)	1000
Q maximal discharge (m^3/s)	0.289
ΔZ is the gross head (m)	66
g gravitational acceleration m/s^2	9.81
η_c is the penstock efficiency ≥ 90%	90%

black-out periods arising from load shedding.

Annual energy output and the capacity factor

Energy Output = Power(kW) x (Hours per Day) × 365 Day

= 168 kW × 12 h × 365
= 735 840 kWh

Using the current cost of electricity which stands at US 10c per kWh, this translates to US$73 584 value of electricity which could be realised.

The operation time of 12 h a day as result of the discharge period would give a capacity factor of ½. This could however improve should the water supply improve so that there is water flow round the clock.

Conclusion

The results show that there is great potential for setting up a micro hydro electric generator within the water supply network in the city of Masvingo. Smaller generating capacities have been successfully implemented with the Toris Torrent project producing only 70 kW while the St Jean power house has a generating capacity of 102 kW (Aline and Vincent, 2010). However, the result simply represents the available potential and actual output will be depended upon the choice of the installed technology. Also, it should be noted that the City of Masvingo is currently supplying water for a few hours a day, thus making the available power intermittent. At the same time, such a power generator could be highly useful if implemented as a peaking generator in a situation where electricity supply is critical.

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