EVALUATION OF HYDROPOWER GENERATION POTENTIAL OF ASEJIRE DAM

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Abstract: Nigeria is blessed with abundant natural water resources. These water resources can be harnessed for hydropower generation for the nation or for the neighboring communities surrounding the natural water resources. With the poor power supply experienced in Nigeria this study evaluates the hydropower potential of Asejire dam located in Asejire town, Oyo state. The dam technical details were obtained from the Asejire dam's office; the flow discharge values were evaluated; the head loss in the penstock was calculated using manning's equation and these data were used to evaluate the hydropower potential of the dam. The hydropower generation ability of the dam was 1.425 MW and a Kaplan turbine was selected as a suitable turbine for the small hydropower scheme. Therefore, if the neighboring communities have access to affordable, clean, reliable and sustainable source of energy, then, the Asejire community can experience sustainable development, socio-economically and industrially.

Keywords: Asejire dam, energy, head, power generation and small hydropower scheme

Introduction

Energy is an important infrastructure for national development. It plays a vital role in the economic, social and political development of our nation. Inadequate supply of energy restricts socio-economic activities, limits economic growth and adversely affects the quality of life (Energy Commision of Nigeria, 2003). Although, various forms of energy exist; they can be primarily classified into conventional and unconventional forms of energy, and this primary source of energy is majorly converted into electricity, termed a secondary form of energy. The conventional form of energy is the most consumed form of energy –fossil fuels and the unconventional form of energy is classified as a renewable form of energy. Renewable energy is a form of energy generated from sources which are easily replenished. This form of energy is cleaner and emits less greenhouse pollution compared to their counterparts: Fossil fuels.

Hydropower is a form of renewable energy and is the energy obtained from the force of moving water. The moving water source can be streams, falls, rivers, or ocean waves. Most hydropower sources are from a natural source which depends on the water cycle for continuous existence. Hydropower is derived from the potential energy available from water due to the height difference between its storage level and the tail water to which it is discharged (Manohar & Adeyanju, 2009).

Nigeria is blessed with abundant natural water resources and these water resources can be harnessed for hydropower generation. According to Adejumobi, et al. (2013), the theoretical electrical power ranging from 5.13 kW to 5,000 kW is realizable in Nigeria if the identified small hydropower sites are developed and this is enough to cater for average rural community loads.

Asejire dam is a dam located in Asejire town, Oyo State and it was built in 1972. The dam is fed by river Osun, and was built for water supply purposes. The dam's reservoir is used as a source of water supply to Oyo State. The water height of the dam is 81 ft. and this level is maintained at the peak of the dry season and the spillway opened during the rainy season (OWAS, 2008).

Therefore, the objective of this research is to evaluate the hydropower potential of Asejire dam and make available the power generation capability of the dam. This information can be used for the development of a Small Hydropower Scheme (SHP) which can be used for electric power generation to power the neighboring communities of the Asejire dam.

Classification of Hydropower Schemes

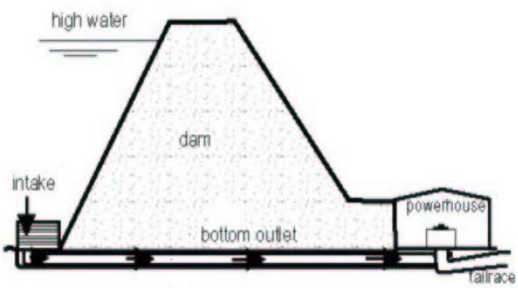
According to European Small Hydropower Association (2004), small hydropower scheme is usually any scheme with a capacity less than 10MW. This classification is not rigid and can vary according to texts.

Also, schemes can be classified as:

- Run-off river schemes
- schemes with the power house located at the base of a dam
- And schemes integrated on a canal or in a water supply pipe.

To construct a dam with its appurtenances for a small hydropower scheme is very expensive. Therefore, most dams used for small hydropower schemes were mainly installed either for irrigation, flood control, or water abstract purposes (European Small Hydropower Association, 2004) like this case study.

The following figure illustrates a scheme with the power house located at the base of a dam.



Source: European Small Hydropower Association (2004)
Fig. 1: Hydropower scheme with the powerhouse located at the base of the dam

Theoretical Analysis

The theoretical analyses illustrated were used to determine flow characteristics and power generation potential of the hydropower scheme. These theoretical analyses were in accordance to the standard of European Small Hydropower Association (ESHA).

Manning's equation for estimating head loss

Manning's equation for a full closed circular cross sectional pipe (European Small Hydropower Association, 2004):

$$\frac{h_f}{l} = s = \frac{10.29 \cdot n^2 \cdot Q^2}{D^{5.333}} \qquad (1)$$

Where: s, is the hydraulic gradient, D is the diameter of the circular pipe, Q is the rate of flow through the pipe, h_f is the frictional loss and l is the length of the pipe, and n is Manning's coefficient.

Manning coefficients, n for several commercial pipes are listed below.

Table 1: Manning coefficient n for several commercial pipes.

Pipe Material	Manning roughness coefficient, n ($s/m^{1/3}$)
Polyethylene	0.009
PVC	0.009
Welded steel	0.012
Cast iron	0.014
Concrete (steel forms with smooth joints)	0.014

Source: European Small Hydropower Association (2004).

Net power

This is the actual power obtainable from the hydropower scheme taken into consideration head loss, and turbine, generator, gearbox and transformer efficiency. The net head is the gross head (H) with the frictional losses (h_f) subtracted. The net power was calculated using the following equation (European Small Hydropower Association, 2004).

$$P = Q \cdot H_n \cdot n_{turbine} \cdot n_{generator} \cdot n_{gearbox} \cdot n_{transformer} \cdot w \qquad (2)$$

Where, P is the net power in kW, Q is the flow rate in m^3/s, H_n is the net head in metres, $n_{turbine}$ is the efficiency of the turbine, $n_{generator}$ is the efficiency of the generator, $n_{gearbox}$ is the efficiency of the gearbox, $n_{transformer}$ is the efficiency of the transformer, and w is the specific weight of water (9.81 KN/m^3).

Materials and Methods

The hydropower generation potential of a dam involves gathering technical information and parameters of the dam, reservoir, penstock size, and hydropower appurtenances. This scheme involved the installation of a power house at the base of a dam with a turbine and a generator in the powerhouse. The dam consists of an intake that controls the flow of water into the bottom outlet which links the headwater and tail water. That is the intake and the power house is connected via a penstock. And a tail race which discharges the water from the power house back into the river.

Asejire dam and reservoir parameters were obtained from Oyo State Water Corporation.

Determination of flow rate

The hydropower potential of a dam is directly dependent on the rate of flow into the turbine. But this rate of flow is limited due to the fall of water from the dam, energy loss in penstock (pipe) due to friction against pipe wall and viscous dissipation, and the reservoir volume.

Rate of flow in penstock

The rate of flow in the penstock is calculated using modified equation (1): Making Q the subject of the equation and according to European Small Hydropower Association (2004), limiting the loss of power to 4%. This is illustrated in the equation below;

$$Q = \sqrt{\frac{H \cdot D^{5.333}}{257.25 \cdot n^2 \cdot L}} \qquad (3)$$

Diameter of intake of dam

The diameter of dam's intake or gate is dependent on the rate of flow and was calculated using the following equation.

$$Q = \frac{\pi . d^2}{4} \cdot \sqrt{2. g. H} \qquad (4)$$

Where: Q is the rate of flow; H is the gross head of the dam; g is the acceleration due to gravity.

Reservoir's volume

The sustainability of the hydropower scheme is dependent on the volume of reservoir; the water consumption of the Oyo state and the hydropower water consumption; and the rate of water recharge of the reservoir. In this case study: Oyo state water consumption and the hydropower water consumption were considered. The technical parameters of the Oyo state water consumption were obtained from Oyo State Water Corporation, Oyo State; and the hydropower water consumption calculated based on the values obtained from the results of equations (3) and (4).

Net head

The net head is the difference between the gross head and the head loss due to friction losses. The net head was the head used in determining the net power of the hydropower scheme. The gross head is the difference between the height of the head water and the tail water of the dam. While the friction losses are the losses that occur during the transmission of the water from the dam through the penstock into the turbine.

The gross head was determined at the Asejire dam's office, Asejire, Oyo State and the friction losses was determined by using equation (1).

Therefore, the net head is defined by the following equation.

Net head (H_n) = Gross head (H) – Head loss (h_f) **(5)**

Net power

The net power is the accessible power that can be gotten from the hydropower scheme based on the net head of the hydropower scheme and the efficiency of the hydropower components. In other words, it is the useful energy that can be harnessed from the hydropower scheme used for the generation of electrical power. The net power was calculated using equation (2).

Turbine selection

The selection of turbine is largely dependent on the head and flow discharge of the hydropower scheme. Selection of turbine can be based on low, medium, and high head scheme. Impulse turbines are more suitable for high head schemes while reaction turbines are suitable for low head scheme with high flow rate ((Douglas *et al.*, 2005).

The following Table was used to aid the selection of a suitable turbine.

Table 2: Comparison of water turbines

	Pelton wheel	Francis	Kaplan
Type number ω_s range (rad)	0.05–0.4	0.4–2.2	1.8–4.6
Operating total head (m)	100– 1700	80–500	Up to 400
Maximum power output (MW)	55	40	30
Best efficiency (percent)	93	94	94
Regulation mechanism	Spear nozzle and deflector plate	Guide vanes, surge tanks	Blade stagger

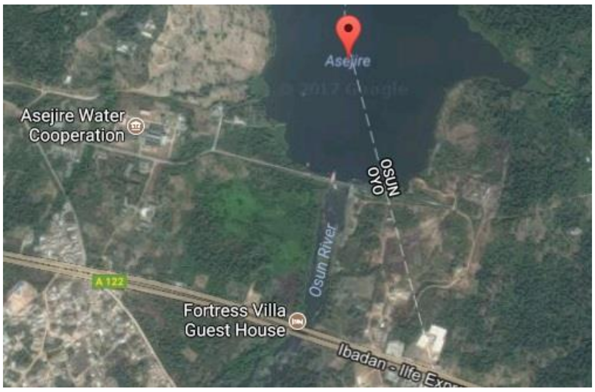
Source: Douglas *et al*. (2005).

Result and Discussion

Asejire dam technical detail

Name of dam: Asejire dam
Location: Asejire, Oyo state
Year built: April, 1970
Built by: Pascal and Ludwig
Purpose of Dam: Water supply
Managed by: Oyo State Water Corporation
Dam crest elevation: 526 ft (160.3 m)
Maximum flood elevation: 519 ft (158.2 m)
Normal pool elevation: 512 ft (156.1 m)
Gate sill (ogee weir) elevation: 479 ft (146 m)
River bed elevation at dam: 446 ft (135.9 m)
Crest to bed elevation: 80 ft (24.4 m)
Dam reservoir volume: 7240 million gallons (32.9 million cubic metres)
Dam length: 2700 ft (823 m)
Reservoir surface area: 38 square miles (98.42 million square metres)
Spillway design flood: 130,000 cfs (3681 m^3/s)
Dam condition: Fair and in operation.

The pictures of Asejire dam is shown in Figs. 2 - 4.



Source: Google Maps (2017)
Figure 1: Map of Asejire dam

Figure 2: Asejire dam (front view)

Figure 3: Asejire dam (rear view) and reservoir

Results of flow rate
The following are the results of the flow rates due to the fall of water from the dam, and rate of flow in the penstock.
Result of rate of flow in penstock
Input of the following parameters, H = Head = 66 ft (19.8 m), L = 150 m, n = 0.012 (Welded steel pipe: See Table 1), D = 1.2 m (48 in) into equation (3).
Rate of flow, Q = 3.1 m^3/s.
Result of diameter of intake of dam
The diameter of the intake or gate of the dam is calculated from equation (4).
Where: Q = 3.1 m^3/s, g = 9.81 m/s^2, H = 19.8m
Intake diameter, d = 0.45 m (18i n)
That is, the diameter of the intake (0.45 m) from the dam leading to the penstock is increased to the diameter of the penstock using a diffuser at the intake gate to reduce the velocity head from the dam to the velocity head in the penstock for the friction losses to be at 4%.
If the diameter of the dam's intake corresponded with the penstock diameter of 1.2 m the flow rate would have been 22.3 m^3/s [calculated from equation (4)] and this would have given a penstock of hydraulic gradient (S) value of 0.279, while the flow rate through the penstock of 3.1 m^3/s gave a hydraulic gradient (S) of 0.0054 [calculated from equation (1)]. This tremendous decrease in hydraulic gradient using the flow rate of 3.1m^3/s gave the opportunity of using a penstock pipe length of up to 150m at a friction loss of 4% of static head. This is achieved by using a diffuser to reduce the velocity from the dam leading to the penstock pipe. That is, the flow rate, 22.3 m^3/ due to the fall potential of the water from the dam would be stepped down to the flow rate of 3.1 m^3/s in the penstock so that losses in the penstock can be as low as 4%.
Reservoir's volume
Hydrographic evaluations estimates that a peak storm occurred at a short duration ranging from 819.87 m^3/s to 1681.34 m^3/s for Osun River at Iwo control station (Adejumo *et al.*, 2016); this hydrograph shows the local refilling of the Osun River caused by the hydrological cycle. And the reservoir level at 81ft is maintained at the peak of the dry season and the spillway opened during the rainy season (OWAS, 2008).
The following Table illustrates the water consumption for Oyo state in which the original purpose of the dam was designed for, with consideration for future expansion of the Oyo state water need; and the hydropower water consumption with consideration to increase in water consumption for the hydropower scheme. The Oyo state water consumption was obtained from Oyo State Water Corporation, while the industries water consumption were obtained from their facilities.

Table 3: Proposed daily water consumptions

Description	Unit
Oyo state water daily consumption	186,000 m^3
Nigerian Bottling Company daily water consumption	1067 m^3
Nigerian Breweries daily water consumption	1333 m^3
Expansion factor for Water consumption	2
Hydropower daily water consumption	267,480 m^3
Hydropower expansion factor, k	3
Total daily water consumption	1,179,240 m^3
Reservoir's storage volume	32,900,000 m^3

Table 3 shows that the reservoir storage can sustainably handle the hydropower water consumption and Oyo state water consumption; and coupled with the hydrograph evaluation shows the recharge ability of the Asejire's reservoir.

Net head

Gross head (H) = Normal pool elevation – River bed elevation = 512 – 446 = 66ft = 19.8m.

From equation (1), head loss (h_f): Where: l = 150m, n = 0.012 (welded steel pipe), Q = 3.1 m^3/s, D = 1.2m. This gave head loss, h_f = 0.81m

From equation (4):

Net head, H_n = 18.99m

The friction losses in the penstock pipe of 1.2m diameter and 150m length caused a 4% drop in the gross head (static head). The friction losses would increase as the length of the pipe increases and would reduce as the diameter of the pipe increases.

Net power

From equation (2):

Where:

Q = 3.1 m^3/s; H_n = 18.99; $n_{turbine}$ = 0.94 (Kaplan turbine); $n_{generator}$ = 0.96 (Industrial-size turbine generators); $n_{gearbox}$ = 0.95; $n_{transformer}$ = 0.96; w = 9.81 kN/m^3

Net power, **P = 475.28 kW**

The generating power potential of the proposed Small Hydropower Scheme (SHP) can be increased by a multiplying factor by having identical penstock pipe size of the same parameters connected to the dam. The multiplying factor is dependent by the volume of reservoir to handle the daily hydropower water consumption. This is given by the following equation:

$$P_m = kP \quad (6)$$

Where: k is the multiplying factor which is the number of identical penstock pipe with the same pipe diameter and having the same flow rate connected to the dam. k was validated by considering the reservoir's volume with respect to the total water supply to Oyo state and the hydropower water need as indicated in Table 3 as the hydropower expansion factor.

Where: k = 3

Therefore, **P_m = 1425.8 kW**

This multiplied the net power, 475.28 kW to give a power of 1425.8 kW. This is a parallel system with each sub-system having the same net power. Efficiency of some of the hydropower components were sourced from Douglas, et al., 2005 and Avallone & Baumeister III, 1996.

Turbine selection

Turbine type: Kaplan turbine

Operating head: up to 400 m

Best efficiency: 94%

Regulation mechanism: Blade stagger

Kaplan turbine was the appropriate turbine selected for the proposed hydropower scheme of the Asejire dam because of its high efficiency at low heads and its considerably high efficiency at percentage of full load.

Conclusion

The above results shows that the hydropower potential of a dam is not fixed but can be varied depending on the rate of flow in the penstock leading into the turbine and the number of identical penstocks connected from the dam to the turbines. But, a design can be made to maximize the dam's generating potential by making the most of the storage volume of the reservoir with respect to the hydrographic evaluation of the site; reducing the head loss in the penstock; increasing the rate of flow and number of identical penstocks leading to the turbine; and use of efficient and suitable hydropower appurtenances.

The dam can conveniently be used for power generation of up to 1.42 Megawatts. This would provide an alternative solution in solving the erratic power supply experienced by the Asejire community and also present an alternate and cleaner source of power generation rather than the use of combustion of fossil fuels being used for power generation by the Industries in Asejire town.

The high return of Investment (RoI) in establishing the hydropower scheme makes it an attractive source of power generation in which the government and private institution can take advantage of by establishing the hydropower scheme and its fairly high cost of appurtenances required.

The electric power supply coupled with the water supply infrastructure would lead to a boost in the industrial growth of Asejire town. Therefore, the small hydropower scheme can be established and used for reliable and sustainable power generation for both the Asejire community and industries in the Asejire town.

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