

A Technical Evaluation Model for the Deployment of Grid-Connected Open Well Pico Turbine Pumped-Hydro Storage Systems in Nigeria

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Abstract

An implementable methodology is proposed for the evaluation of open well-pico turbine pumped-hydro storage systems in Nigeria. Open wells are available in many Nigerian homes and thus present opportunities for pico turbine pumped-hydro storage (PTP-HS) for electricity supply augmentation at individual homes. Hence a model to evaluate the potential of PTP-HS for electricity supply of household and resource characteristics of an available open well has been developed. The model includes a procedure for determining suitable sizes and technical specifications of PTP-HS components based on household energy demand. The model also covers assessment of yield potential of an open well for PTP-HS based on water volume capacity, expected duration of system operation, and system storage capacity. The model was applied to a case study and the results were presented and discussed accordingly. Thus, the study has unveiled a procedure that can aid in evaluating the technical feasibility of open well resources for PTP-HS in Nigeria.

Keywords

Open Well, Pico Turbine, Pumped-Hydro Storage, Grid Electricity and Nigeria.

1. Introduction

Acute shortage of electricity with an epileptic power supply to homes is a major problem in Nigeria. Many homes in Nigeria are deprived of adequate electricity and this has plunged them into a very poor state of living. While household energy consumption constitutes around 45% of the world electricity consumption (Pearce and Ahn 2017), daily electricity supply from the grid to Nigerian homes averages 5 hours (Awofeso 2011). This is short of demand and often limits residents' daily activities. To cover-up for this lack, home owners in Nigeria have resulted to the use of private diesel and petrol generators (Babatunde et al. 2019). However, fossil fuel generators have been detrimental to the environment.

Diesel and petrol generators alongside other fossil fuels using equipments have been reported as major sources of carbon emissions which have increased global warming, climate change and consequently flood (Schaller et al. 2016). Also, they have been instrumental to both air and noise pollution in residential areas and, many chronic lung diseases and death (Aliyu et al. 2013). According to Adebayo (1991), the death toll resulting from private fossil fuel generator usage has increased in Nigeria. All these, have made private fossil fuel generators to be unsafe in residences and thus, creating rooms for adopting energy storage systems (ESS).

ESS stores electricity during the period of excess supply and dispatched it when required. One common way of storing electricity is through batteries. However, the option is burdened with limitations such as high cost, self-discharging and high frequency of replacement (Chen et al. 2013; Kabir et al. 2018). These limitations have made battery storage system unsustainable and hence paved the way for the consideration of Pumped-Hydro Storage technology.

Pumped-Hydro Storage (P-HS) is an energy storage technique which utilizes the potential energy in water for energy storage purpose (Amirante et al. 2017). It operates by pumping water from the lower to the upper reservoir and generates energy when the water is allowed to fall through a turbine (Guney et al. 2017). Application of P-HS system at large energy storage has been demonstrated and it has been suggested in a residential application using an open well

(Anilkumar et al. 2017) which are available in many residential buildings in Nigeria. While this proposition appears to be an interesting way to cover up the shortage of electricity supply, its adoption requires an effective evaluation to ascertain the capacity of the technology. That is, there is a need to assess the technical feasibility of open well for pico-turbine pumped-hydro storage (PTP-HS) in Nigerian houses.

Numerous research efforts have been demonstrated towards energy storage concepts and pumped-hydro storage system (P-HS) specifically. Albeit, mostly for large energy storage (Stenzel and Linssen, 2016) and their applications, installation, maintenance and simulations. For example, Chatzivasileiadi et al. (2013) and Ferreira et al. (2013) described the applications of electrical energy storage technologies in buildings. Rehman et al. (2015) presented a technical review of a P-HS. Alqub (2017) designed a large scale energy storage using P-HS for a water treatment plant while Akour and Al-Garalleh (2019) designed P-HS for Jordan. Katsaprakakis et al. (2008) presented P-HS operation for an isolated power generation. Also, integration of P-HS system with wind and solar is another dimension in the application of P-HS. For instance, Ma et al. (2014) and Ma et al. (2015) considered the mathematical modeling of solar and P-HS while Katsaprakakis et al. (2012) introduced the integration of P-HS with wind energy.

With the wide application and effectiveness of P-HS, it has attracted residential application and thus, requires evaluations of its potential in Nigerian homes. Studies of Silva and Hendrick (2016) have unveiled the P-HS technological application at the residential level in France while Anilkumar et al. (2017), Pali and Vadhera (2018a) in India. Also, Pali and Vadhera (2018b) proposed a system of pico pumped-hydro storage (PTP-HS), grid and RES to minimize the cost of electricity. Considering the growing interest of the technology, there is a need to evaluate its technical feasibility in Nigeria as a step towards the adoption of new technology.

To the best of our knowledge, this kind of analysis appears to be scanty in Nigeria. Also, models to analyze the technical viability of open well for PTP-HS have not been dealt with exhaustively in the body of evidence. In the light of these, the study aimed at developing a model to evaluate open well for a grid-connected Pico Turbine pumped-hydro storage (PTP-HS) in Nigerian homes.

2. System Configuration

The proposed system is targeted at augmenting electricity from the grid in Nigerian homes. This is to be achieved through electricity storage during the period of grid supply and dispatch when it is no longer available. As described in Figure 1, the system is made up of pico turbine generator, hydraulic pump, water valves, penstock, tank (upper reservoir), the open well as the lower reservoir, and connected to the grid through the home it is serving.

The household meets its electricity demand through grid supply and PTP-HS at different periods. The system operates based on two modes which are pumping (charging) and generation (discharging) mode. The two modes are characterized by the period of grid electricity supply and no grid electricity supply. During the period of grid electricity supply, energy is fed to the house and the pump to convey a specific volume of water from the open well (lower reservoir) to the tank (upper reservoir). The pumped water is released through pico turbine to generate electricity when energy supply from the grid stops. The two operations are referred to as pumping (charging) and generating (discharging) respectively and the operation cycle is repeated daily to cover up the hours for which grid electricity is not available.

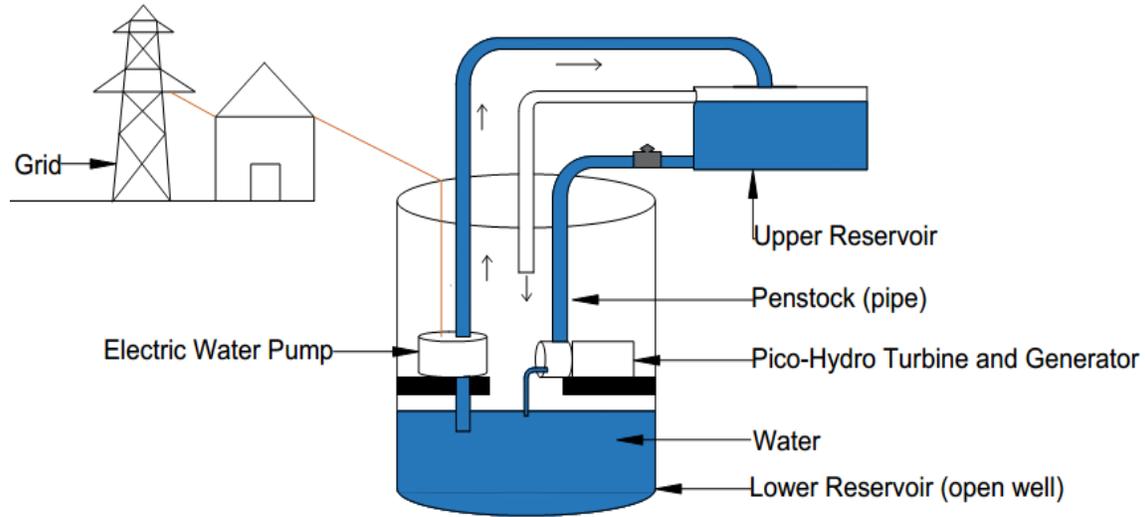


Figure 1. Grid-Connected Pico-Turbine Pumped-Hydro Storage (PTP-HS)

3. Methodology

In this section, a methodology to evaluate an open well for a PTP-HS is presented. The developed methodology applied an analytical modeling approach to propose an evaluation method. The model structure includes analysis methods for technical specification and components suitable for specific electricity demand and, evaluation criteria to measure the capacity of an open well for PTP-HS. For the purpose of modeling, we assumed the following to be known; the depth of the well from earth surface to the maximum height of water in the open well; the volume of water in the open well; daily energy demand of the household and duration of daily electricity supply from the grid.

3.1 Power, Time and Energy Storage Required

Given that there are two modes of PTP-HS operation (generation and pumping), the average duration of daily electricity supply from the grid H_{UT} and duration of daily electricity demand (i.e. 24 Hours), we describe the duration required for PTP-HS operation H_{PTP-HS} as;

$$H_{PTP-HS} = 24 - H_{UT} \quad (1)$$

The energy required from pico turbine pumped-hydro storage for the period of no electricity supply from the grid Φ_R is described as;

$$\Phi_R = \text{Daily energy demand} - \text{Energy demand during Supply from Grid} \quad (2)$$

$$\Phi_R = ED_{LS} \left[\frac{24 - H_{UT}}{24} \right] \quad (3)$$

To estimate the power rating required for the generator, we used the equation of energy as described in equation 4;

$$E = P * T \quad (4)$$

Taking E from equation 4 as daily energy demand ED_{LS} and T the number of hours in a day, we rewrite equation 4 as;

$$ED_{LS} = P * 24 \quad (5)$$

While the power generation equation of the pumped-hydro storage P is given as;

$$P = P_H * \eta_G \quad (6)$$

The hydraulic power required for turbine P_H is demonstrated in equation 7. Thus, by substituting equation 5 into equation 6 we have;

$$P_H = ED_{LS} / 24\eta_G \quad (7)$$

3.2 Generation Mode (Turbine)

The require flow rate Q_T for a hydro turbine to generate suitable P_H is estimated from the hydraulic equation which is described in equation 8;

$$P_H = \rho g H_N \eta_T Q_T \quad (8)$$

$$Q_T = \frac{P_H}{\rho g H_N \eta_T} \quad (9)$$

By substituting equations 7 into equation 9 we have;

$$Q_T = \frac{EDLS}{235200(H_G - H_{LT})\eta_T\eta_G} \quad (10)$$

However, to determine Q_T we require the head loss H_{LT} at the turbine mode given the gross head H_G (i.e. depth of open well). Thus, we applied the Manning equation for head loss (Singhal and Kumar 2015) as described in equation 11.

$$H_{LT} = \frac{L_P V_T^2 n_P^2}{R_T^{4/3}} \quad (11)$$

To determine the flow velocity V_T in a circular pipe, we applied the continuity equation of moving fluid in a circular pipe as described in equation 12;

$$Q_T = A_T V_T \quad (12)$$

By simplifying equation 12 to include the equation of area of a circular pipe, we have equations 13 and then 14 accordingly;

$$Q_T = \frac{\pi D_T^2}{4} V_T \quad (13)$$

$$V_T = \frac{4Q_T}{\pi D_T^2} \quad (14)$$

while the hydraulic radius R_T for round conduit with full or half flowing water is estimated as;

$$R_T = \frac{D_T}{4} \quad (15)$$

Then, to estimate the inner diameter D_T of the pipe at the turbine mode, Lundi-Bundschu empirical equation for the diameter of a pipe for flow rate Q_T and gross working head H less than 100 m (Bulu 2019) in equation 16 was applied.

$$D_T = \sqrt[7]{0.05(Q_T)^3} \quad (16)$$

The equations 10-16 were solved iteratively to estimate a desired Q_T . The initial value of H_{LT} is set at zero and solved until an equal H_{LT} is achieved in two successive iterations. Thus, the desired Q_T is the working flow rate for the power demand and as well used to estimate the required volume of water V_{MAX} . Therefore, V_{MAX} is estimated as;

$$V_{MAX} = Q_T * 3600 H_{PTP-HS} \quad (17)$$

Also, the required capacity for upper reservoir R^{UR} is assumed to have the same volume as the required volume of water since the upper reservoir is enclosed from atmospheric interference.

$$R^{UR} = Q_T * 3600 H_{PTP-HS} \quad (18)$$

3.3 Pumping Mode (Pump).

In the case of pumping mode, the flow rate required for pumping is estimated as the function of the available volume of water V_A and the average duration of electricity supply from the grid H_{UT} . Based on the relationship, we estimate Q_P as described in equation 19 and project the pumping operation to be performed within 90% duration of grid electricity supply. Note, the flow rate at pumping mode is dependent on the available water in an open well or the required volume of V_{MAX} for the system. As a result, we estimate the flow rate for the pump Q_P using equation 19 which considers the minimum value between V_A and V_{MAX} and duration of grid electricity supply

$$Q_P = \frac{\min[V_A:V_{MAX}]}{3240H_{UT}} \quad (19)$$

The state of charge of the storage system SOC at any time can be evaluated as the function of the required flow rate in pumping mode, time function of the duration of grid electricity supply and the required volume of water V_{MAX} ;

$$SOC = \frac{Q_P * T}{V_{MAX}} * 100\% \quad (20)$$

Where; $T \rightarrow 0$ to H_{UT}

In a similar procedure to generation mode (equations 10-16), we estimated the D_P , V_P , R_P and adapted equation 16 for pumping mode and, when equation 19 was substituted we have;

$$D_P = \sqrt[7]{0.05 \left[\frac{\min[V_A:V_{MAX}]}{3240H_{UT}} \right]^3} \quad (21)$$

Therefore, the flow velocity at pump mode V_P is described in equation 22 and by substituting equation 19 into 22 we have 23. Aso, equation 24 and 25 describe R_P and H_{LP} at pump mode respectively;

$$V_P = \frac{4Q_P}{\pi D_P^2} \quad (22)$$

$$V_P = \frac{4[\min[V_A:V_{MAX}]]}{3240\pi D_P^2 H_{UT}} \quad (23)$$

$$R_p = \sqrt[4]{0.05 \left[\frac{\min[V_A:V_{MAX}]}{3240H_{UT}} \right]^3} \quad (24)$$

$$H_{LP} = \frac{L_P V_P^2 n_P^2}{R_p^{4/3}} \quad (25)$$

The required power rating of the pump is estimated as;

$$P_{PS} = \frac{\rho g Q_P H_G + H_{LP}}{\eta_P} \quad (26)$$

3.4 Evaluation Criteria for Open Well

Once all the required components and the technical specification have been evaluated using equations 10-26, the open well can then be evaluated. Firstly, we assessed the water volume capability WVC of the open well using a direct comparison method between the maximum required volume of water V_{MAX} for specific energy and the available water V_A :

$$WVC = \frac{\text{Available Volume of Water}}{\text{Required Volume of Water}} \quad (27)$$

$$WVC = \frac{V_A}{V_{MAX}} * 100\% \quad (28)$$

The possible hours H_p of PTP-HS operation considering the available water V_A in the open well and the percentage of time that the resources of the open well can functionally support the proposed PTP-HS is estimated as equations 29-31. For H_p , equation 17 was modified by replacing V_{MAX} with V_A and H_{PHS} with H_p where H_p is a variable and the unknown that is being solved for;

$$V_A = Q_T H_p 3600 \quad (29)$$

$$H_p = \frac{V_A}{3600 Q_T} \quad (30)$$

Thus, the percentage time \widetilde{H}_p that the available resources can cover is estimated as;

$$\widetilde{H}_p = \frac{H_p}{H_{PHS}} * 100\% \quad (31)$$

And the energy that can be generated based on the characteristics of the open well and the size of the evaluated components is estimated as;

$$\phi_C = \rho g (H_G - H_{LT}) \eta_T \eta_G Q_T H_p \quad (32)$$

Therefore, the system storage capability SSC is estimated as;

$$SSC = \frac{\phi_C}{\phi_R} * 100\% \quad (33)$$

3.5 Energy Balance Equation.

The energy balance equations were used to analyze anticipated energy consumption at pumping mode and percentage anticipated for the house and pump operation (charging) consumption during grid electricity supply. To evaluate the anticipated energy consumption at pumping mode, anticipated duration of pumping ϕ in the system was estimated using the relationship between flow rate at pumping mode Q_p and the minimum value between V_A and V_{MAX} as described in equation 34;

$$\phi = \frac{\min[V_A:V_{MAX}]}{3240 Q_P} \quad (34)$$

The anticipated daily energy consumption of the pump is estimated as a function of the power requirement of the pump and the anticipated duration of pumping;

$$ED_{PS}(t) = P_{PS} * \phi \quad (35)$$

The anticipated total energy consumption ED_T during H_{UT} is estimated as the fraction of daily energy demand and the anticipated energy consumption of the pump. This is described in equation 36 as;

$$ED_T(t) = 0.042 H_{UT} ED_{LS}(t) + ED_{PS}(t) \quad (36)$$

Thus, the anticipated percentage for household consumption β and pump consumption γ at pumping mode is estimated as described in equation 37 and 38 respectively;

$$\beta = \frac{0.042 H_{UT} ED_{LS}(t)}{0.042 H_{UT} ED_{LS}(t) + ED_{PS}(t)} * 100\% \quad (37)$$

$$\gamma = 1 - \beta \quad (38)$$

4. Results and Discussion

In this section, a case study of a Nigerian home with an available open well, a known daily duration of electricity from the grid and household demand was considered to demonstrate the application of the proposed methodology. Table 1 presents the parameters from the case study;

Table 1. Parameters from a Case Study in Nigeria

Parameter	Value	Description
V_A	40.5 m ³	The maximum volume of water available in open well at the peak of the rainy season.
H_G	11 m	This is measured from the height of maximum volume of water with a tolerance of 0.5m to the earth surface level.
ED_{LS}	24kwh	The daily energy demand of the house.
H_{UT}	5 Hours	The daily duration of electricity from the grid.
η_T	0.84	Turbine Efficiency
η_G	0.84	Generator Efficiency

Applying the equations described in 1-38 using the parameters from table 1 we have the following results in Tables 2-6. Tables 2 and 3 presents the evaluated size and technical parameters at generation mode (turbine) and pumping mode required for PTP-HS in the case study.

Table 2. Results for the Generation Mode (Turbine)

Parameters	Turbine
Flow Rate	0.0135 m ³ /s
Flow Velocity	1.6173 m/s
Hydraulic Radius	0.0257 m
Head Loss	0.3054 m
Volume of Water Required	924.9 m ³
Required Upper Reservoir	924.9m ³

In Table 2, the flow rate required to meet the energy demand of the household was estimated as 0.0135m³/s at a differential height (gross head) of 11m. Based on the estimated flow rate, the maximum water required to match energy demand is 924.9 m³. This volume of water represents the potential energy that is used as storage in PTP-HS system. Also, the upper reservoir required to store the volume of water is 924.9 m³.

Table 3. Results for the Pumping Mode

Parameters	Estimated Values
Flow Rate	0.0025 m ³ /s
Flow Velocity	1.27 m/s
Hydraulic Radius	0.0125 m
Head Loss	0.4945 m
Anticipated Power of Pump	402.31Watt
State of Charge after 5 hours	4.87%

Similarly, Table 3 presents the results for the pumping mode using equations 19-26. From the table, the flow rate required for the pump to transfer water from the open well (lower reservoir) to the upper reservoir (tank) within the period of electricity from the grid is 0.0025 m³/s. Using this flow rate and the depth from which the water is pumped to the surface level where the upper reservoir is positioned, the power required for the hydraulic pump is 0.402 kW. However, since the available water in our case study is less than the required volume of water, the state of charge of the system after the period of pumping (charging) is 4.87%.

Table 4. Evaluation Results from the Case Study

Parameter	Value	Description
WVC	4.38%	This describes the capacity of available water in the open well for the anticipated energy storage.

H_p	50 Minutes	This describes the duration for which the system can operate considering the estimated peak demand of the home in consideration.
\bar{H}_p	4.37%	The percentage time that the PTP-HS system can cover considering the hours of storage required.
ϕ_R	19kwh	The daily energy demand from PTP-HS.
ϕ_C	0.988kwh	The amount of electricity that can be dispatched based on the open well PTP-HS
SSC	4.39%	The storage capability of the system of open well-PTP-HS.

From Table 4, the result showed that the available open well in the case study has a very low capacity to meet the electricity demand of the household. The storage capacity is around 4.39% and the system will function for 50 minutes at a rated peak of 1.19kw. Also, out of the energy demand by the house which is 19kwh, open well-PTP-HS is projected to be able to generate only 0.988kwh.

Table 5. Results of anticipated Electricity Consumption at Pumping Mode

Parameter	Value	Description
φ	5 Hours	Anticipated Duration for Pumping (Charging)
ED_{PS}	2.01 kWh	Anticipated Energy Consumption at Pumping Mode
ED_T	7.05 kWh	Anticipated total energy consumption of home and pump during the period of grid electricity supply.
β	71.48%	Percentage of energy anticipated for household consumption at pumping mode.
γ	28.52%	Percentage energy anticipated for hydraulic pump consumption at pumping mode.

In Table 5, the analysis of anticipated energy consumption during PTP-HS operation was presented. The pump is expected to operate for 5 Hours and would consume 2.01 kWh given the anticipated power of the pump (see table 3). This takes the anticipated total energy consumption of the house within the period of grid electricity supply to 7.05kwh. The 71.48% of the anticipated energy would be for the household immediate consumption while 28.52% of the anticipated energy consumption at pumping mode is directed towards storing energy for the period when there is no grid electricity supply.

However, the open well in our case study demonstrated that it can only support PTP-HS at the estimated power for 50 minutes. This is very small considering the 19 hours required from PTP-HS operation. Therefore, the anticipated system is inadequate for the demand of the household in the case study.

A further analysis was carried out to investigate the influence of an increase in the gross head (depth of the open well) on the system while other parameters are kept constant. This analysis was carried out to evaluate the scenarios of deeper open wells for PTP-HS.

Table 6. What If Analysis for Gross Head H_G

$+\Delta H_G$	20%	40%	60%	80%	100%
H_G (m)	13.2	15.4	17.6	19.8	22
Q_T (m ³ /s)	0.0112	0.0096	0.0084	0.0076	0.0068
H_{LT} (m)	0.386	0.470	0.558	0.6489	0.7428
V_{MAX} (m ³)	766.08	656.64	547.56	519.84	465.12
Q_P (m ³ /s)	0.0025	0.0025	0.0025	0.0025	0.0025
H_{LP} (m)	0.59	0.69	0.79	0.89	0.99
P_{PS} (kw)	0.48	0.56	0.64	0.72	0.80
SOC (%)	5.87	6.85	8.22	8.66	9.67
WVC (%)	5.29	6.17	7.4	7.79	8.71
H_p (Hours, Minutes)	1:00	1:10	1:20	1:29	1:39
\bar{H}_p (%)	5.28	6.17	7.05	7.79	8.71
ϕ_R (kwh)	19	19	19	19	19
ϕ_C (kwh)	1.0	1.16	1.33	1.49	1.65
SSC (%)	5.24	6.11	6.98	7.84	8.70

ϕ (Hours)	5	5	5	5	5
ED_{PS} (kwh)	2.4	2.8	3.2	3.6	4
ED_T (kwh)	7.44	7.84	8.24	8.64	9.04
β (%)	67.74	64.29	61.17	58.33	55.75
γ (%)	32.26	35.71	38.83	41.67	44.25

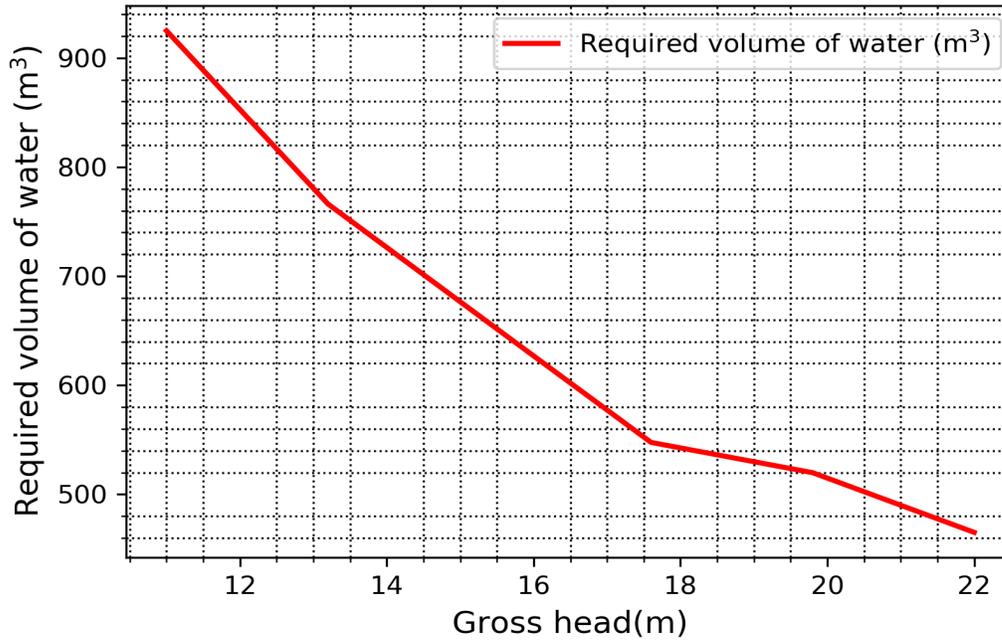


Figure 2. Influence of gross head on the required volume of water

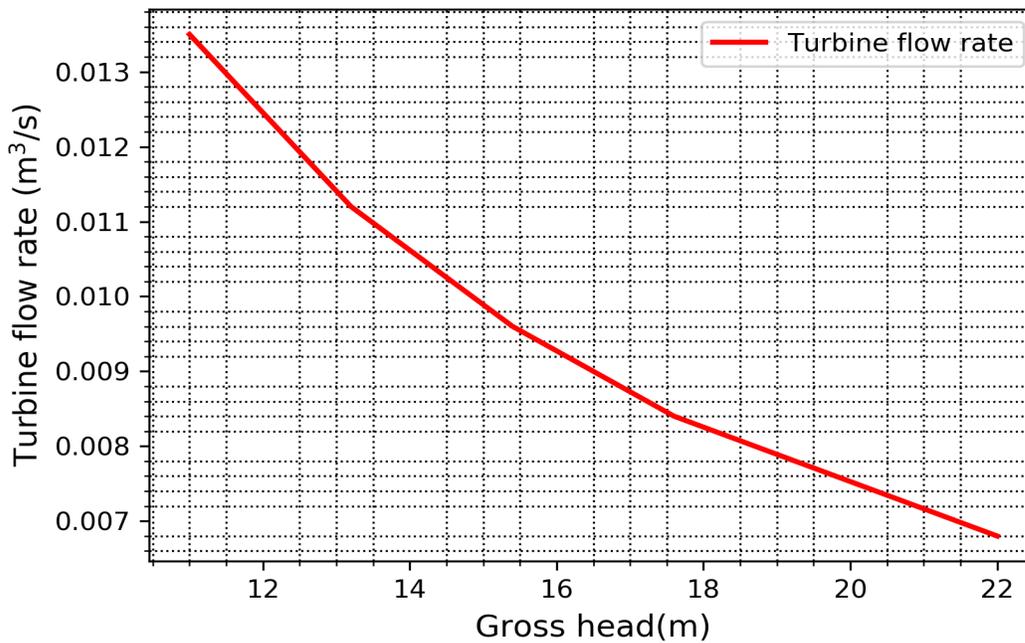


Figure 3. Influence of gross head on the Flow Rate for Turbine

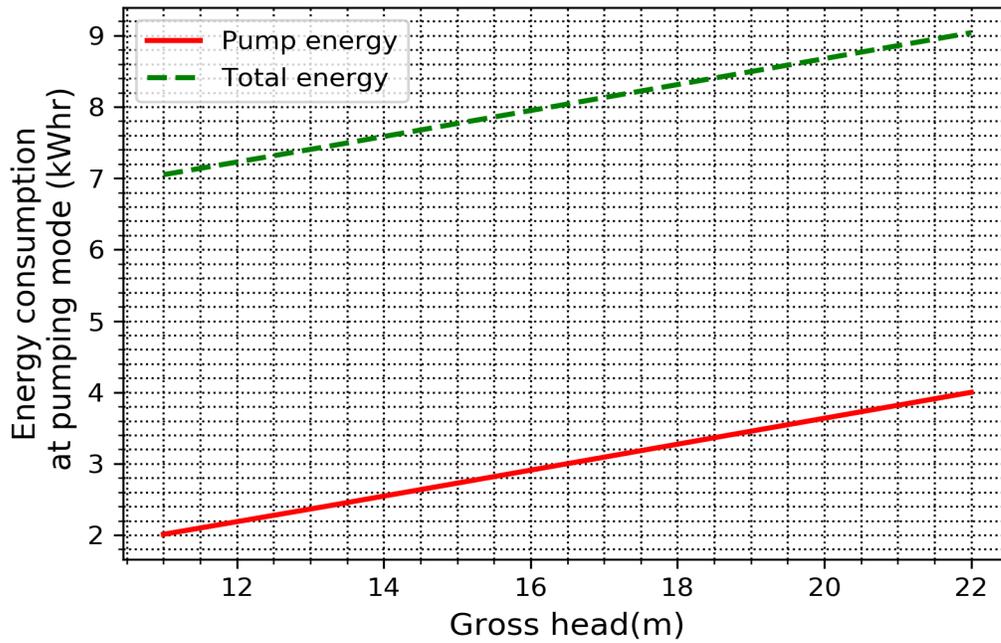


Figure 4. Influence of gross head in energy consumption of pump and the total energy consumption

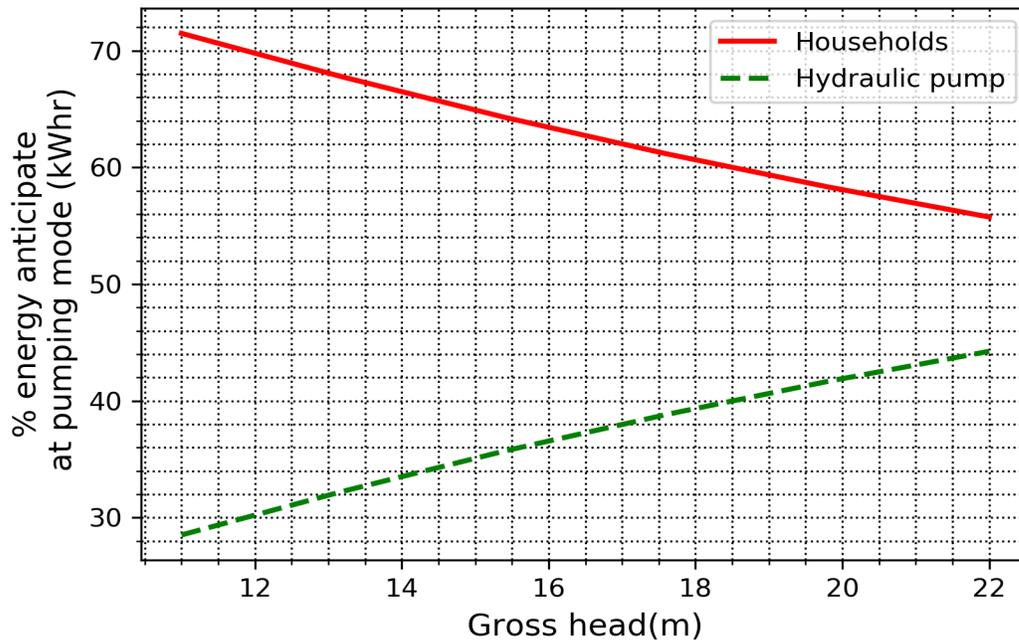


Figure 5. Influence of gross head on the percentage energy consumption anticipated for households and pump

Table 6 presents the result of analysis for PTP-HS at a 20% stepwise increasing of the gross head of the open well while all other parameters remain constant. In the table, it was observed that when the gross head increased, the storage capacity of the open well increased accordingly. Also, this influenced the possible hours for which the system can serve the household at the estimated power rate. The result indicates that if the depth of the well gets deeper, the possible hours of generation will increase as the case was in Table 6. For instance, increasing the gross head from 11m

to 15.4m led to an increase in the possible hours of operation of the open well-PTP-HS from 50 minutes to about 1 hour 10 minutes. Although the energy demand of the house could not be met totally when the gross head was increased to 100% (22m), there was a notable increase in the hours of operation. At 100% increment of the gross head, the open well would be able to support PTP-HS operation for about 1 hour 39minutes.

Also, it is to be noted from Figure 2 that the volume of water required for the energy demand of the home decreased as the gross head increased. From Table 6 and Figure 2, when the gross head was increased from 13.2 to 17.6, the volume of water required to satisfy the demand of the home in this study decreased from 766.08m³ to 547.56m³ and a further decrement was noticed with increasing gross head. Although the maximum water available in the open well of the case study was not sufficient for the household energy demand, further evaluation showed that by increasing the depth of the open well (i.e. gross head), the capability of the system can increase.

Figure 3 demonstrates that, with an increase in the depth of open well (i.e. gross head), the flow rate that would be required for turbine can be lowered and thus, the operation hour of PTP-HS could be elongated. That is, the period for the household to enjoy energy supply from PTP-HS would increase since the rate at which the potential energy of the stored water is depleted has reduced. This implies that a situation where the open well has a limited volume of water and/or restriction for the upper reservoir (i.e. tank), the differential height between the upper reservoirs and the lower reservoir can be altered to increase the hour of operation of PTP-HS.

In Figure 4, it can be observed that the increase in the gross head directly increases the power rating requirement for the hydraulic pump and consequently increases the energy consumed during pumping mode. This has an implication on the total energy consumption during the pumping mode and would equally influence the energy that would be drawn from the grid electricity supply. Also, Figure 5 demonstrated the percentage of energy anticipated for household and pump consumption during the pumping mode. The percentage showed that at a lower gross head, the percentage of energy anticipated for household consumption is very high. However, as the gross head increases the percentage of energy anticipated for household and pump consumption at pumping mode tends towards being equal. For example, Table 5 showed that the percentage for household consumption at pumping mode is 71.48% and for the pump is 28.52%. Meanwhile, when the gross head (i.e. open well) was increased to 22m, the percentage changed to 55.75% and 44.25% for household and pump consumption respectively. This implies that while an increase in gross head enhances energy storage of PTP-HS and its system's capacity, it does require more energy supply from the grid electricity for the pumping mode. That is more energy is required for the charging process when the gross head becomes increased.

5. Conclusion

In this study, a methodology for evaluating open well for pico turbine pumped-hydro storage in Nigeria homes has been proposed alongside the procedure for sizing the turbine and pump parameters for PTP-HS. The concept is to develop a simplified step to step guide which can aid homeowners and/or designers on the assessment of open well for PTP-HS. The applicability of the developed model was demonstrated by applying it to a case study and the results were presented accordingly. From the study, it was observed that open well has the potential to store energy and can support households in Nigeria for electricity supply. However, the capacity of the system might become insufficient as a result of long hours of lack of grid electricity supply to Nigerian houses. Thus, developing such PTP-HS using open well might require the integration of another energy supplying systems to cater for the long period of lack of grid electricity supply.

Also, the importance of open wells with sufficient volume of water and the suitable depths towards PTP-HS was demonstrated. Critical factors such as flow rate and available water volume demonstrated to be instrumental and would be necessary for system optimization. Thus, the economic implication of this method compared to other methods of augmenting the grid electricity supply in Nigeria would be required to further evaluate its viability and sustainability.

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