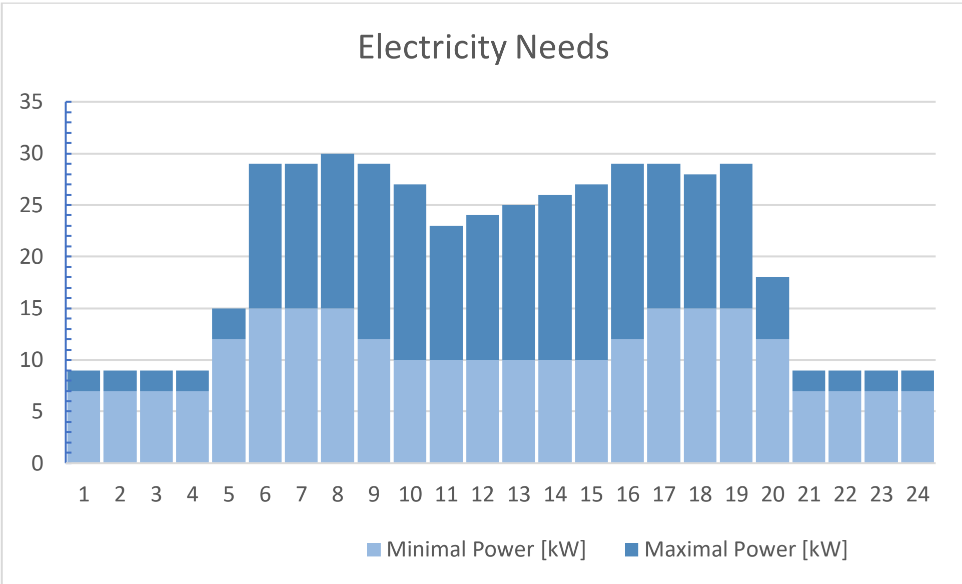
CONTEXT

The location of the studied site is in Mikalayi in Kasaï Central in the Democratic Republic of Congo (6°00'31.3"S 22°19'16.6"E). The site is off-grid meaning electricity is not available from the network. However, there are inhabitants in the zone and infrastructure like hospital, schools, churchs, shops, craftworkers… that require electricity.

The figure below illustrates the daily needs of the community in terms of electrical power.



With lifespan exceeding 30 years, micro-scale hydropower systems are commonly employed to provide electricity in isolated or rural regions. Unlike their large-scale counterparts, these setups are typically built without the need for dams or expansive reservoirs. Instead, they are powered by a local river, utilizing a weir to control the water flow, with minimal or no water storage.

Figure 1 : Weir and intake to the power plant.

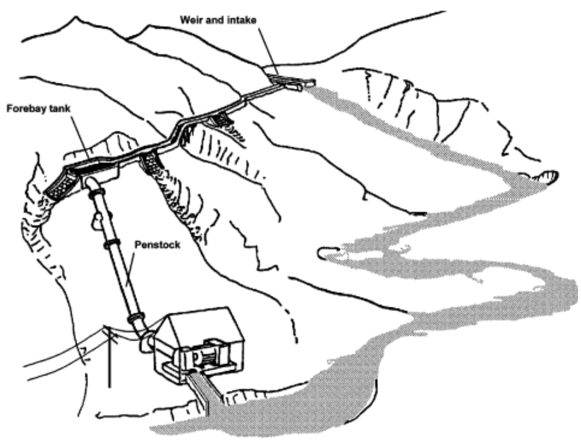


Figure 2 : Hydropower plant from 2002_Paish

In Mikalayi, there is a micro-hydropower plant that produces electricity. For this hydropower plant, capital expenditures for the whole turnkey hydropower plant (civil engineering works, electro-mechanical equipment and transmission line) have been estimated at 500k€ while operating cost are 5k€ per year all inclusive.

The river feeding the hydropower site has a nominal discharge of 2350 m^3/h and falls down over a height of 14.2m. After a 31m length × Ø630 mm pipe, a turbogenerator unit, illustrated in Figure 3, converts the available hydraulic power into electricity and provides the electricity to consumers through a 1,000 V distribution powerline over a length of 1,800 m.

Figure 3 : Turbo-alternator unit.

However, the amount of electricity produced is contingent on the availability of water at any given time, making it dependent on seasonal weather patterns. Even when the power plant is well-designed, a frequent mismatch between energy production and consumption might occur. In the site of Mikalayi, at least 3 months per year, during the dry season, the river has a minimal discharge rate that is only half of its nominal value.

To overcome electricity shortage, storage is required. Pumped hydro energy storage (PHES) is recognized as one of the most cost-effective energy storage technologies. The principle is quite simple: during off-peak demand, PHES pumps back water to an upper reservoir and stores potential energy exploitable by the hydraulic turbine when it is needed. To decrease costs, the same equipment can be used to pump and turbine water. At Mikilayi, a PaT (Pump as Turbine) scenario is envisaged. Indeed, a field located at a geodetic head of 25m from the power plant could be exploited as the upper reservoir. Civil works could be done with the help of local workers and all the equipment (pump, pipe…) could be find in Kananga that is a city quite close to the site.

Your opinion about the pertinence of the energy storage solution is asked for. Your answer could be guided by questions in the section below. These questions can be solved with the help of documents in the appendices.

QUESTIONS

A. NOMINAL POWER DELIVERED FOR THE CONSUMERS

1. What is the hydraulic power available on the site? What happens to this power if it is not used?
2. Identify the different losses of the conversion system (from water to low voltage electricity)? Estimate them roughly – give the order of magnitude.
3. What is the nominal electrical power available? What is the minimum electrical power available during the dry season?

B. CONVERSION TECHNOLOGY

4. What are the mininal and maximal daily consumers' needs in terms of energy ?
5. Is a hydroelectric plant relevant to meet these needs? What is the LCOE ? What would have been other options ?
6. What type of turbine can be installed on the site, what are these advantages/disadvantages?
7. In the photo in Figure 3, identify the elements that you can recognize and describe their function.

C. STORAGE TECHNOLOGY

8. What are the storage requirements in terms of energy ? in terms of reservoir dimensions ?
9. Is the proposed technology relevant from a social and environmental point of view ?
10. Can the pump with Ø300 described in the technical sheet presented in the appendices, in Figure 6, be suitable for direct coupling to a 4-pole generator (1500 rpm)? What would be the characteristics (efficiency, power) of the PAT as a pump, as a turbine ?
11. How to calculate the LCOE of the stored kWh? What would be the significant parameters?
12. What are energy storage alternatives ? Are they more suitable for the application ?

APPENDICES

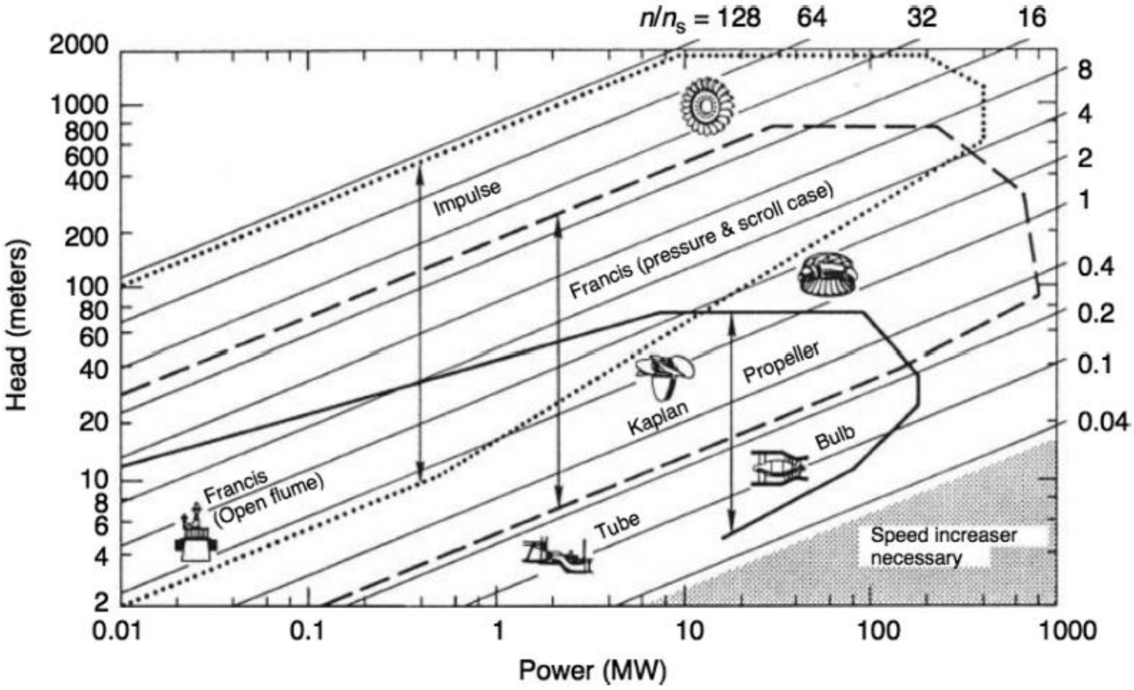


Figure 4 : Turbine selection chart from Gulliver & Al. (1991)

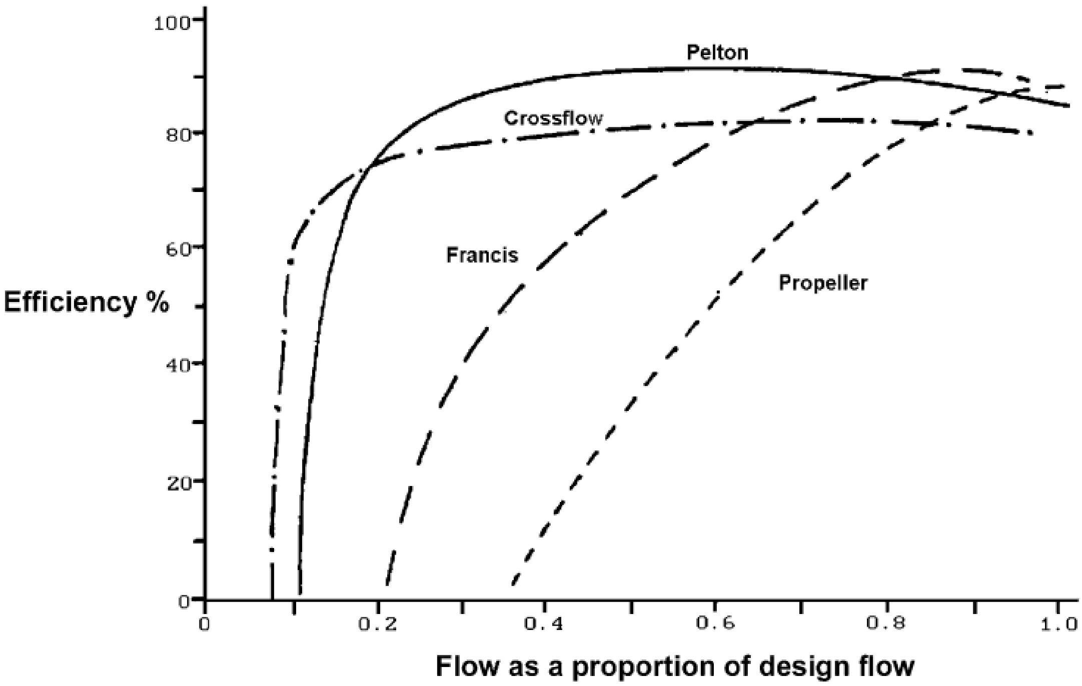


Figure 5 : Evolution of efficiency with the flow (2002-Paish)

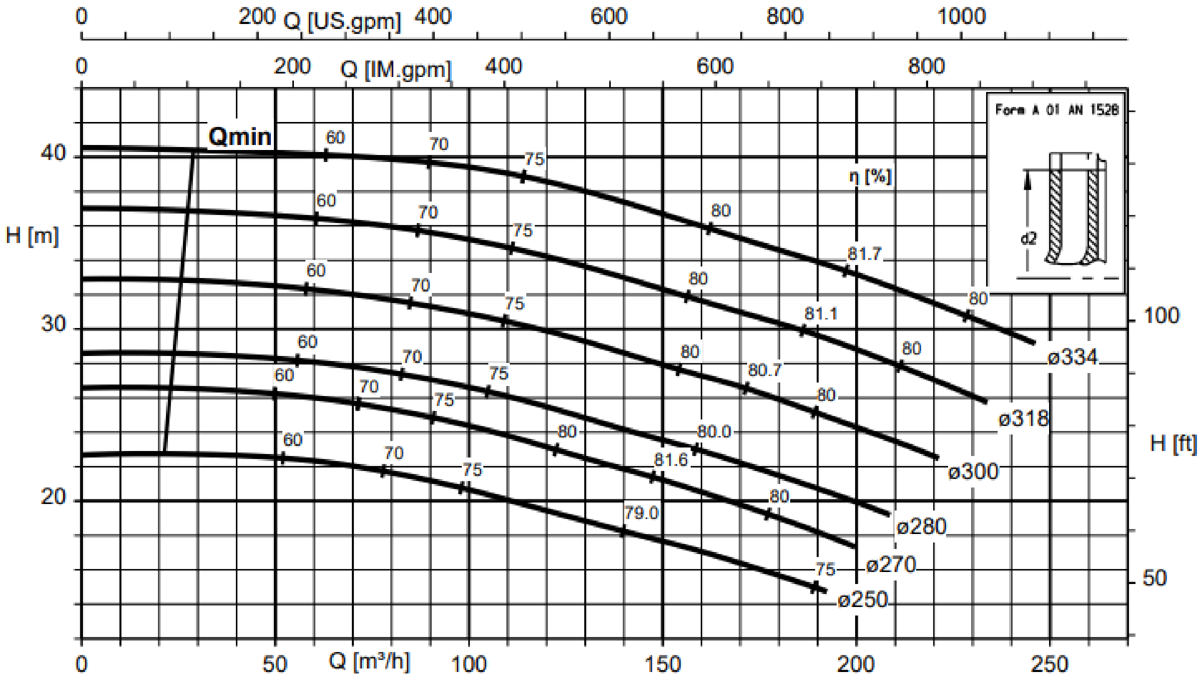


Figure 6 : data-sheet for the considered PAT (Ø300)

AFFINITY LAWS

The affinity laws are used to express the relationship between variables of a rotary machine. They linked together operating conditions for similar equipment from a state '1' to a state '2'.

Let be :

- N [rpm], the rotational velocity
- D [m], the diameter of the runner
- H [m], the pressure at the inlet (turbine) or at the outlet (pump)
- Q [m^3/h], the flow rate
- P [W], the power
- '1' the known working conditions
- '2' the unknown working conditions

Affinity laws can be written as :

(N1/N2) = (D2/D1) * (H1/H2)^(1/2)
(N1/N2) = (Q2/Q1)^(1/2) * (H1/H2)^(3/4)
(N1/N2) = (P2/P1)^(1/2) * (H1/H2)^(5/4)

PERFORMANCE PREDICTION AND SELECTION OF PAT

1. Based on the characteristics of an available pump from the manufacturer's catalogue, the working conditions of the pump are estimated: N_p, Q_p, H_p, eta_p

2. The performance prediction models are estimated

- Specific velocity for the pump mode : N_sp = N_p*(Q_p)^0.5 /(H_p)^0.75

- Prediction models are the link between best efficiency points from pump to turbine modes :
    - h = 5.196(N_sp)^-0.323
    - q = 3.127 (N_sp)^-0.219

3. The working conditions of the selected pump in reversed mode rotating at the pump rotational speed are found. @N_t = N_p :
    - Q_t = q*Q_p
    - H_t = h*H_p,
    - eta_t = eta_p

4. The available head are site dependent, the affinity laws could be applied to determine the characteristics at another head than H_t :

- Flow rate : Q2(Q1,H1,H2)
- Power : P2(P1,H1,H2)