

Original article

Comparative analysis of mini hydro turbines for Bumaji Stream, Boki, Cross River State, Nigeria



Roland Uhunmwangho, Mathias Odje, Kenneth E. Okedu*

Department of Electrical and Electronics Engineering, University of Port Harcourt, Nigeria

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ABSTRACT

The study has the major objectives of examining the performance of various mini hydro turbines for the Bumaji Stream in Cross River State. The study was based on the Stream data obtained during peak and lean rainy seasons of the year and the estimated hydroelectric power potentials of the River. The performances, technical and economic feasibility of the sampled hydro turbines was also carried out using RETScreen Renewable Software. The result of the analysis show that the cheapest power was generated by a Cross Flow Turbine which delivered 0.67 MW at \$100.8/MWh with an internal rate of return 20.4%, a net present value of \$358 a payback period of less than 5 years and a yearly savings of \$63,000. However, the Kaplan turbine made more technical sense as it delivers 0.748 MW at \$106.2/MWh with an internal rate of return 19.3%, a net present value of \$295, a payback period of 5 years and a yearly savings of \$52,000.

Introduction

In Nigeria, the persistent activities of pipeline vandals, shortage of gas supplies from flow stations to power stations, lack of adequate generation, transmission and distribution system have plunged electric power generation in recent times to an all-time lowest capacity. The power shortage situation in Nigeria has put a huge pressure on the few functioning generating stations and on the Federal Government of Nigeria [1–3]. As a result of this seemingly unending pressure, there has been a calculative effort by both the government and private sectors to harness a more sustainable, reliable and clean alternative sources for power generation in a deliberate attempt to meet the government basic obligation of providing adequate power that would engender the desired socio-economic development of the nation. Small hydro power scheme is one of such clean energy sources being given attention and turbines are unavoidably required for the operations of Mini hydro power stations [4–7]. Hydro turbines convert the energy in falling/flowing water into mechanical energy (Shaft rotational power). The moving water strikes the turbine blades just like with a water wheel and in-turn spins a shaft coupled to the turbine runner. In comparison with waterwheels, the turbines are very compact in relation to their output, they have fewer gear control and lesser construction material [8]. Hydro turbines are classified based on the principle of operation and can be either impulse or reaction turbines as described below.

The impulse turbine

The water pressure is first converted to kinetic energy in the form of a high-speed jet of water ejecting through nozzle. The water jet hits the turbine blades, transferring its momentum to the blades surface before falling to the tail-water with weaker pressure [9,10]. With impulse turbine, jets of water strike directly on the turbine blade or bucket surfaces. This pressurized jet then results in rotational motion (and hence mechanical energy) which can be converted into electrical energy by a generator. The impulse turbine runner operates in air, driven by jets of water and the water remains at atmospheric pressure before and after making contact with the runner blades. Impulse turbines are generally well suited for high head, low flow applications. Pelton, Turgo and Cross flow (Banki) turbines are classified as impulse turbines.

The reaction turbines

Water pressure exerts a direct force on the turbine blade surface which transfers energy to the turbine and results in a corresponding pressure drop in the water as it exits the turbine. The reaction turbines exploit the oncoming flow of water to produce hydrodynamic lift forces to propel the runner blades [11–13]. Unlike the impulse turbine, the reaction turbines have runners that always function within a completely water-filled casing and all reaction turbines have a diffuser known as a draft tube below the runner via which the water is exited.

* Corresponding author.

E-mail addresses: kenneth.okedu@uniport.edu.ng, kenokedu@MIT.EDU (K.E. Okedu).

Table 1
Classification of small hydropower schemes [15].

Turbine runner	Head classification		
	High (above 50 m or 160 ft)	Medium (10–50 m or 32 ft–160 ft)	Low (below 10 m or 32 ft)
Impulse	Pelton Turgo Multi-jet Pelton	Cross flow Turgo Multi-jet Pelton	Cross flow
Reaction		Francis (Spiral Case) Kaplan Pump-as-Turbine (PAT)	Propeller Kaplan Francis (Open-flume)

The draft tube slows down the discharged water and decreases the static pressure underneath the runner and thus increases the net head. Reaction turbines are generally better suited for lower head, higher flow applications. The reaction turbine can be a Propeller (or variable blade propeller known as Kaplan), Francis turbine and Pump-as-turbine (PAT) [14].

Hydro turbine selection criteria

The choice of a turbine to be considered for small hydro schemes depend mainly on the pressure head available and the design water flow [16]. Furthermore, the classification and selection of turbines is determined mainly by their principle of operations as well as the pressure heads and designed flow. Judging based on information provided in Table 1 and in Fig. 1, it is likely to have more than one turbine meeting the selection criteria for a particular hydro scheme. The economic and financial considerations for each turbine alongside with each turbine advantages and disadvantages mainly influenced the selection of a particular turbine in such a case. Fig. 1 presents a chart to guide

one in the selection of an appropriate turbine suitable for a given design head and flow.

Technical design parameters

Apart from analyzing the river discharge and water head, the designer has to determine the optimum turbine type and series, the number of power generating units, the runner diameter, rotational speed, and runner axis elevation [18].

There are two approaches used in selection of turbines; the thumb rule and scientific approach.

The Thumb Rule: Turbines are being selected on the basis of a given water head and flow conditions of a river in comparison with standard chart showed in Fig. 1.

The Scientific Approach: Considering the intricacy of designing site specific hydro turbines, the initial turbine technology selection should be hinge on technical, social, environmental and economic factors. In practice, turbines have been selected mainly on the basis of the specific speed. The specific speed (n_s) is the speed in r.p.m. at which a turbine of homologous design would operate, if the runner were to reduce to a size which would develop one metric horse power under one-meter head. It is given by the following relation [19]:

$$n_s = \frac{n\sqrt{P*1.358}}{H^{5/4}} \quad (1)$$

where,

n_s = Specific speed of turbine in r.p.m

n = Rated speed of turbine in r.p.m

P = Turbine Output in kW, and

H = Rated head in meters.

Once the specific speed (n_s) is ascertained, the chart in Fig. 2 may be

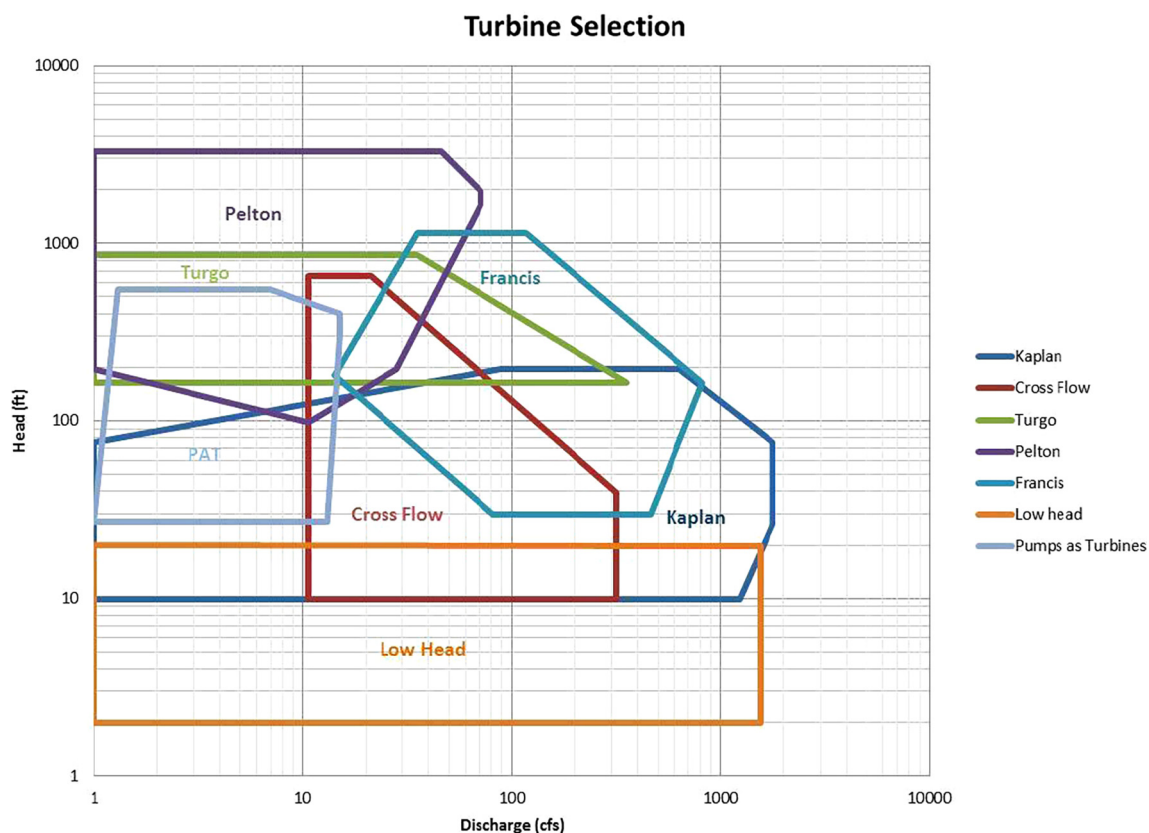


Fig. 1. Turbine Selection with respect to Water Head and Flow [17].

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