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Numerical and experimental investigations on efficient design and performance of hydrokinetic Banki cross flow turbine for rural areas

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ABSTRACT

Micro hydrokinetic energy scheme presents an attractive, environmentally-friendly and efficient electric generation in rural, remote and hilly areas. However, this scheme is yet to be fully discovered, as researchers are still searching for solutions for the main problems of low velocity of current in the open flow channels and low efficiency of hydrokinetic turbines. This research proposes a novel system configuration to capture as much kinetic energy as possible from stream water current. This system, known as bidirectional diffuser augmented (BDA) channel, functions by utilizing dual directed nozzles in the flow and is surrounded by dual cross flow/Banki turbines. It is also important to obtain the efficient design parameters of the turbines to use in the current configuration. The appropriate angle is important in order to guide the flow to touch the blades more perpendicularly to capture as much torque and power as possible. Hence, experimental and numerical investigations have been carried out in this research paper to study the performance characteristics of the CFT configuration applied in BDA system and investigate the effects of blades' inlet and outlet angles of CFT runners on the internal flow characteristics and efficiency. In this study, four different runners with various inlet and outlet angles of two CFT have been investigated. The CFD results have been validated with the experimental work and proven acceptable with flow pattern and performance characteristics. The results of the current study conclude that the maximum power coefficients (Cp) of 0.612 and 0.473 for lower and upper turbines are recorded for best runner angles of Case 3.

1. Introduction

Rural electrification of many developing countries is very costly, especially in areas with economic problems (Elbatran et al., 2015a). Using micro hydropower can be the perfect solution to overcome the economical and operational problems (Laghari et al., 2013). Micro hydropower plants can be used to produce suitable electrical power for homes, plantations and farms in small villages (Elbatran et al., 2015b). They are more predictable when the supply of water is enough (Mohibullah et al.,), and they also have positive environmental impacts (Teuteberg, 2010). Hydrokinetic is a new type of micro hydro-power, which extracts kinetic energy from the flow of water in open channels, rivers or canals by deploying hydrokinetic turbines without any facilities like weirs, barrages or falls; this scheme is not deployed with any kind of reservoir (Okot, 2013; Yaakob et al., 2014; Herman Jacobus et al., 2014; Kumar et al., 2011; Elbatran et al., 2015c; Chamorro et al., 2013; Shabara et al., 2015). This application attracts investments in hilly and isolated areas' electrification due to its easy construction and low cost. It also exploits small hydrological areas (Rojanamon and Taweep, 2009). Many researches focus on studying the water stream technology from both flow and turbines systems perspectives by considering improvements on the open channel flow and suitable turbine systems utilized in these micro channels to be used in the micro power production. The free stream flow systems normally need a higher amount of mass flow with low pressure to be able to extract energy, but the conventional current turbines are more suitable for high pressure and flow rate (Ki-Pyoung et al., 2012). Hence, many studies tried to develop unique and new technology designs and configurations to capture as much kinetic energy as possible.

Using nozzles is the most efficient choice to accelerate the flow because it can increase the harnessed power. Nozzles can be utilized in

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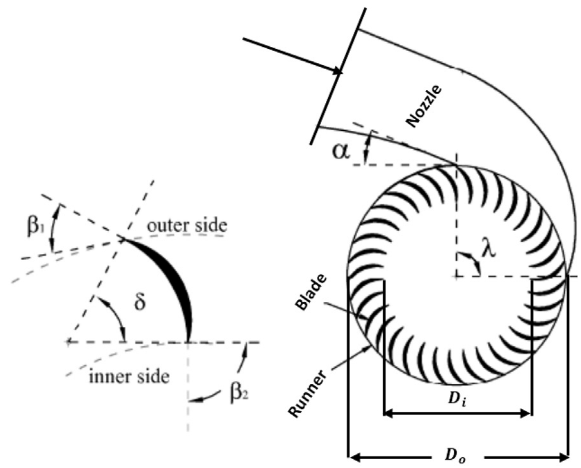

Fig. 1. Main geometrical parameters of CFT (Sammartano et al., 2013).

Table 1
The recommended dimensional and performance parameters of CFT can be drawn from the literature review (Referring to Fig. 1).

Main parameters	Recommended values
Diameter ratio 12-04-18	0.6–0.68 (Olgun, 1998; Shahram et al., 1988; Desai and Aziz, 1994; Choi et al., 2009, 2010; Prasad et al., 2014; Kim et al., 2015)
Angle of attack (α)	16°-22 ° (Sammartano et al., 2013; Mockmore and Merryfield, 1949; Shahram et al., 1988; Desai and Aziz, 1994; Totapally and Aziz, 1994)
Inlet blade angle (β_1)	30° (Olgun, 1998; Desai and Aziz, 1994; Totapally and Aziz, 1994; Choi et al., 2008)
Exit blade angle (β_2)	90° or below (Olgun, 1998; Desai and Aziz, 1994; Totapally and Aziz, 1994; Choi et al., 2008)
Central angle of blade (δ)	61.5° (Sammartano et al., 2013)
Number of blades (Z)	25-30 (Sammartano et al., 2013; Nakase et al., 1982; Shahram et al., 1988; Desai and Aziz, 1994; Totapally and Aziz, 1994)
CFT efficiency (η) (hydropower stations)	68%–88% (Olgun, 1998; Mockmore and Merryfield, 1949; Nakase et al., 1982; Durgin, 1984; Hothersall, 1985; Ott and Chappel, 1989; Desai and Aziz, 1994; Totapally and Aziz, 1994; Kaunda et al., 2014a; De Andrade et al., 2011)
CFT efficiency (η) (wave, tidal and hydrokinetic generation)	40%–55% (Elbatran et al., 2015a; Ki-Pyoung et al., 2012; Choi et al., 2009, 2010; Prasad et al., 2014; Kim et al., 2015)

streams of micro channel flow or ducted around turbines (Elbatran et al., 2016). Deploying nozzles in channels accelerates the flow and increases the water's kinetic energy. Khan et al. (2013) conducted analytical and numerical investigations to enhance the flow by utilizing convergent nozzles for flow in open water channels. The power extracted from channels mainly depends on the velocity of the in-stream water flow; thus, geometrical parameters of the nozzles will have major effects on the flow patterns and velocity. By focusing only on one parameter which was the inlet angle of the convergence nozzle, Khan et al. (2013) studied the flow patterns through the velocity and pressure behavior contours. The convergence nozzle succeeded in accelerating the water flow by increasing velocity at the nozzle plan. It is important to investigate the effects of nozzle geometrical parameters, such as diameter ratio, nozzle configuration and nozzle edges shape on the flow characteristics in micro scale channels through parametric study. Consequently, Elbatran et al. (2015d) concentrated on determining the flow field pattern, water velocity values, pressure distribution, turbulence effects, volume flow rate and the amount of power that could be captured with respect to different geometrical parameters of the deploying nozzles. These also included the effects of the free surface. Elbatran et al. (Elbatran et al., 2015), also studied the helical channel flow properties from the hydraulic perspective in order to utilize these channels in the renewable energy field. Moreover, Elbatran et al. (2017) proposed a ducted nozzle configuration around Savonius turbine in water channel to increase the efficiency of the turbine.

1.1. Cross flow turbines/Banki turbines

The turbine is one of the most costly parts in the budget of micro power scheme; it can even reach up to 30% of the total budget, where the cost depends on the type of turbine (Elbatran et al., 2015b). Cross flow or Banki turbine is more preferable in micro hydropower scales compared with other turbines, based on its performance and cost options (Olgun, 1998). Since it can be familiarized with various ranges of flow rate and lower head, it is more proper for low head schemes (Ghosh and Prelas, 2011; Ossberger GmbH Co, 2011). The cross flow turbine performance depends on geometrical parameters, such as runner diameter ratio, nozzle entry arc, guide vanes, number of blades, angle of attack and the inlet and exit blade angles as a described in Fig. 1 α is the angle between the inlet velocity and the tangent direction of the turbine runner inlet, and are the outer and inner diameters of the runner, and are the inlet and outlet blade angles with respect to the tangent direction of the outer and the inner diameters, Z is the blade number and t is the blade thickness, λ is the angle of the arc available for the discharge inlet along the runner outer circumference, and δ is the central angle of the blade.

Mockmore and Merryfield (1949) study is one of the oldest and the most important studies on cross flow turbines. They defined the hydraulic efficiency of the turbine and the relation between the angle of attack (α) and the inlet blade angle (β). Their study also suggested a value of 16° for the angle of attack, and the maximum efficiency of 68% was obtained in this study. Nakase et al. (1982) studied the effects of the nozzle shape on the performance of cross flow turbines. The maximum efficiency of this study was 82%, with the recommended number of blades as 26. Khosrowpanah et al. (Shahram et al., 1988) experimentally studied the CFT performance through different geometrical parameters under various flow and head conditions. Their results demonstrated that the maximum efficiency of the CFT increased as the nozzle entry arc increased or the aspect ratio of the runner decreased. In their research, the recommended number of blades, diameter ratio and angle of attack were 15, 0.68 and 16°, respectively. Furthermore, the peak value of efficiency occurred at 0.52 speed ratio. Moreover, Durgin and Fay (Durgin, 1984), Hothersall (1985) and Otto and Chappel (Ott and Chappel, 1989) reported that the maximum efficiencies were 66%, 75% and 89%, respectively.

Fiuzat et al. (Fiuzat and Akerkar, 1991) proved that the turbine's second stage contributes more significantly to the power production than reported in the analytic literature. Desai and Aziz (1994) concluded that the maximum efficiency of CFT decreased with the increase in the angle of attack in the range of 22°–32°. It also increased when the number of blades increased from 15 to 30. In their study, the recommended diameter ratio was 0.6 and the exit angle was 55°. The peak value of efficiency was also almost 88% at speed ratio of near 0.55. The results of Hara et al. (Totapally and Aziz, 1994) presented that the turbine was more efficient by using nozzles that were narrower than the runner. It is possible when the angles of attack are between 22° and 24°, the number of blades is 35 and the exit angle is smaller than 90°. According to Olgun (1998) study, the highest efficiency of 72% was obtained at 0.67 runner diameter ratio. Moreover, the study selected 30° and 90° for the blade inlet and outlet angles, respectively.

Kokubu et al. (2013) proved that the CFT efficiency was improved in the presence of guide vane with current plate. Kaunda et al. (2014a) experimentally investigated the performance of CFT to enhance the design of a Cross flow turbine, as an appropriate technology for small-scale power generation. Hence, their study was depending on conditions other than the 'best efficiency point'. It also explored the influence of nozzle opening parameter as well as the characteristics of the