

The word 'ZERO' is rendered in a large, hollow, green-outlined font. The 'O' is partially obscured by a large, stylized turbine graphic that spans across the top and middle of the page. The turbine has a central vertical shaft and several curved blades or segments. A solid green horizontal band is positioned behind the text.

ZERO

Small-scale Water Current Turbines for River Applications

January 2010

Kari Sørnes



About ZERO

Zero Emission Resource Organization is an environmental organization dedicated to reducing climate change by demonstrating and gaining acceptance for zero emission energy solutions. We believe a zero emission solution exists for all energy use. Our mission is to work consistently for these solutions.

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Summary

The purpose of this report is to get an overview of the existing technology of water current turbines with a unit power output of about 0.5-5 kW.

Water current turbines, or hydrokinetic turbines, produce electricity directly from the flowing water in a river or a stream. No dam or artificial head is needed to produce the small-scale power output. Several of the devices mentioned in the report may have application in tidal waters, ocean currents and manmade channels, but the scope of this report is limited to applications in free-flowing rivers.

Reviews of the most common existing turbine technologies are outlined. The two most common small-scale hydrokinetic turbine concepts are axial flow turbine and cross-flow turbine. Of importance for the power production is whether the turbine is ducted or not. Where to place the turbine must also be well considered.

The report summarizes the commercial market which exists in this field and considers some previous experiences in rural areas. Several companies from different parts of the world are presented with their concept. To find the companies which are established and emerging within this field, a web-based search is performed. Previous reports dealing with this subject are also reviewed.

Small-scale hydro power from water current turbines is considered to be reliable and ecologically friendly. Because of the low cost and the longevity of micro hydro, developing countries may manufacture and implement the technology to help supply the needed electricity to small communities in remote areas. Discussions on performance analysis and modelling issues are beyond the scope of this work.

1 Introduction

The natural power of a running river or a stream has been of interest for electricity production for many years. The technology of small-scale hydro power is diverse, and different concepts have been developed and tried out. This report will focus on water current turbines with a unit power output of about 0.5-5 kW. These turbines are supposed to be used for domestic electricity applications such as lighting, battery charging, or for the use of a small fridge. The units are small, cheap and often owned, installed, and used by a single family.

Water current turbines, also called hydro kinetic or in-stream turbines, have received a growing interest in many parts of the world. Two main areas where hydrokinetic devices can be used for power generation purposes are tidal currents and river streams. This report will focus on water current turbines for river applications. These turbines generate power from the kinetic energy of a flowing stream of water without the use of a dam or a barrage. Water current turbines can be installed in any flow with a velocity greater than 0.5 m/s [1]. Because of low investment costs and maintenance fees, this technology is cost effective in comparison to other technologies. The continuous supply of electrical energy is also an advantage in comparison to solar power or other small-scale renewable technologies. This kind of small-scale hydropower is considered environmentally friendly, meaning that the water passing through the generator is directed back into the stream with relatively small impact on the surrounding ecology.

Small-scale water current turbines can be a solution for power supply in remote areas. Because of the low cost and durability of this kind of hydro power, developing countries can manufacture and implement the technology to supply the needed electricity to small communities and villages [2].

There are different kinds of small-scale hydropower. The term “pico hydropower” is said to be water power up to 5kW and is a smaller version of the more established term; micro hydropower. Pico hydropower is usually used when we think of hydropower on a regular basis, where the power is made by falling water and an artificial water-head. The report will not consider this type of hydropower. The report will mainly focus on kinetic “in-stream” hydro turbines. These turbines produce electricity from the free-flowing water in a river or stream and do not rely upon a water-head to produce electricity.

For the scope of this report the focus was on applications in free-flowing rivers, although several of the devices may have applications in tidal waters, ocean currents and man-made channels.

Short reviews of some of the existing turbine technologies are outlined. The paper will also look at the commercial market in this field and consider some experiences already made in rural areas in different parts of the world. In order to find the existing technologies and companies with viable concepts, a web-based search is accomplished. Earlier written reports are also reviewed.

Discussions on performance analysis and modelling issues are beyond the scope of this work.

This report have been made with financial support from Norad - Norwegian Agency for Development Cooperation.

2 The Technology of Water Current Turbines

Water current turbines, or hydrokinetic turbines, produce electricity directly from the flowing water in a river or a stream. The energy flux of the water stream is dependent on the density, cross-sectional area and velocity cubed (eq. 2.0.1). A number of different concepts have been developed to utilise this power throughout the world. While turbine systems are considered prime choices for such conversion, other non-turbine possibilities are also being pursued with interest. At present, the non-turbine systems are mostly at the prototype stage. [3] This report will thus exclusively focus on turbine systems.

$$P = \frac{1}{2} \rho C_k A V^3 \quad (2.0.1)$$

- P = Power (watt)
- ρ = Water density (kg/m³)
- C_k = Power coefficient
- A = Turbine area (m²)
- V = Velocity of water (m/s)

2.1 Conversion and Operation

When considering the possible use of a water current turbine on river applications, several issues are of concern with regards to the power production performance. The next chapter will give a general introduction to the technology of this field.

2.1.1 Conversion Schemes

Several hydrokinetic conversion concepts have been developed through the years. The two most common small-scale hydrokinetic turbine concepts are axial flow turbine and cross-flow turbine. The axial concept has a rotational axis of rotor which is paral-

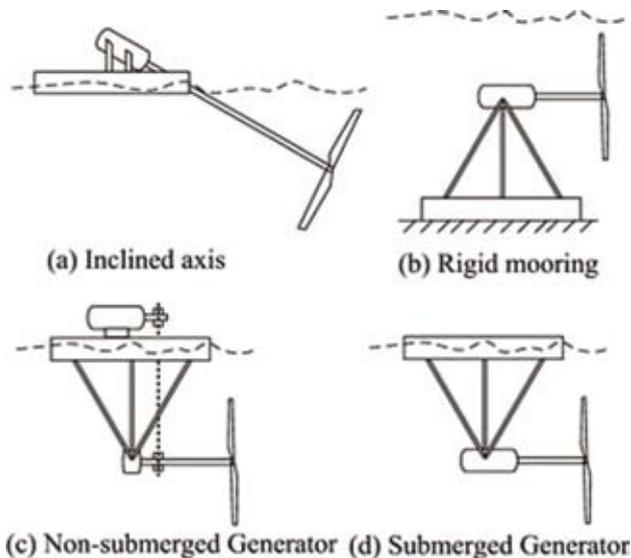


Figure 2.1.1.1: Axial-flow (horizontal) turbines [4]

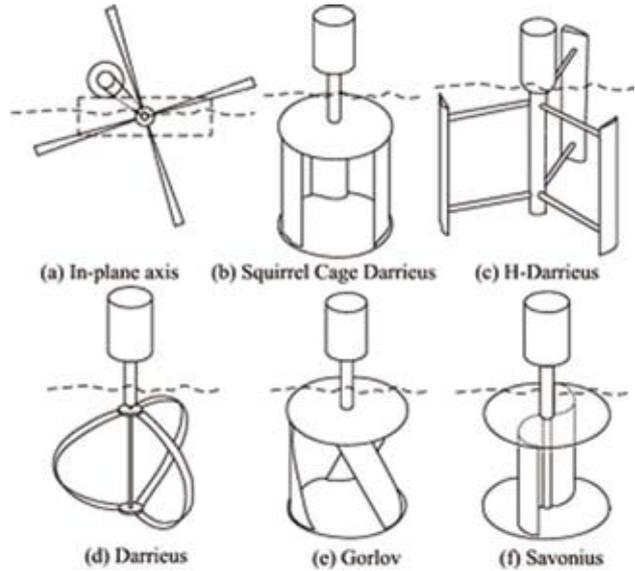


Figure 2.1.1.2: Cross-flow turbines [4]

lel to the incoming water stream. This is illustrated in figure 2.1.1.1. The inclined axis turbines (a) have mostly been studied for small river energy converters. The horizontal axis (b, c and d) turbines are common in tidal energy converters and are very similar to modern day wind turbines from design and structural point of view. [4]

The cross-flow concept on the other hand, has a rotational axis of rotor which is parallel to the water surface, but orthogonal to the incoming water stream [3]. The advantage of cross-flow turbines is that they can rotate unidirectional even with bi-directional fluid flow. They can be divided into two groups:

1. Vertical axis, with an axis vertical to the water plane. Different types are illustrated in figure 2.1.1.2. In the vertical axis domain, the use of H-Darrieus or Squirrel Cage Darrieus is rather common. Instances of Darrieus turbines being used to produce hydro-power are nearly non-existent. The Gorlov turbine is another member of the vertical axis family, where the blades are of helical structure. Savonius turbines are “drag type” devices, which may consist of straight or skewed blades. The disadvantages associated with vertical axis turbines are: low starting torque, torque ripple, and lower efficiency. [4] These turbines may not be self-starting and therefore some kind of external starting mechanisms need to be adopted.
2. In-plane axis, with an axis on the horizontal plane of the water surface. These are better known as floating waterwheels. The in-plane turbines are mainly drag based devices and said to be less efficient than their lift based counterparts. The large amount of ma-

terial usage can be another problem for such turbines. [4]

Axial flow turbines are self-starting and the issue of start up is not significant. However, they come with a price of higher system cost owing to the use of submerged generator or gearing equipment. Vertical axis turbines, especially the H-Darrieus types with two or three blades are reasonably efficient and simpler in design, but not self-starting. Mechanisms for starting these rotors from a stalled state could be devised from mechanical or electromechanical perspectives. [15]

2.1.2 Augmentation

Whether the turbine is ducted or not is of great importance for the performance of the turbine. Ducts or diffusers are engineered structures that elevate the energy density of a water stream as observed by a hydrokinetic converter [3]. The duct, or augmentation channel, increases the possible total power capture significantly. In addition, it may help regulate the speed of the rotor and reduce problems caused by low-speed drive train design. A consideration for these devices is of high significance primarily because of two opposing reasons. First, there is the potential of increasing the power capacity, and hence reduce the cost of energy. On the other hand, there may be a lack of confidence concerning their survivability and design [3]. Figure 2.1.2.1 illustrates some of the types.

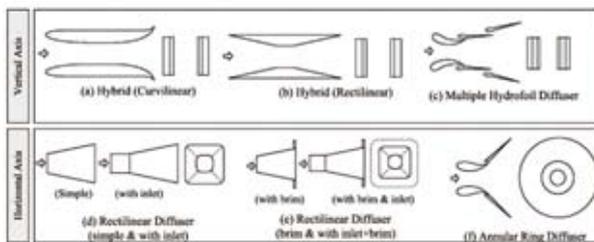


Figure 2.1.2.1: Examples of ducts/diffusers [4]

2.1.3 The Flow of the River and Siting Considerations

The best performance and the highest power production is made by a smooth linear flow of water at high velocity [5]. The flow characteristic of a river stream has a stochastic variation, both seasonal and daily, and where to put the water current turbine must therefore be well considered. A positive aspect of the flow of rivers is that it is unidirectional, which eliminates the requirement for rotor yawing.

For a hydrokinetic converter, the level of power output is directly related to flow velocity. The volumetric flow information may be available for the location, but the water velocity varies from one potential site to the other depending on the cross-sectional area. [3] The placement of a hydrokinetic device, in relation to a channel cross-section, is a very significant component for two basic reasons. First of all, the energy flux in the surface of a stream is higher than that of the stream on the bottom. In addition, this quantity takes diverse values depending on the distance from the shore. In a smooth channel, the water current is fastest at the centre, but in a river this may vary depending of the bottom. Therefore, the water velocity has a localized and site-specific profile, and where the rotor is located dictates the amount of energy that can be produced. [3] Second, in a river there are competing users of the water stream. This could be boats, fishing vessels, bridges, etc., and these might reduce the effective usable area for a turbine installation [6]. There could also be varying types of suspended particles and materials like fish, rock, ice, etc. in the river [4].

Properly placing a hydrokinetic turbine requires an understanding of what influences the kinetic energy or velocity of the water at any point in the river. This can be studied further in the report Siting Considerations for Kinetic (In-Stream) Hydro Turbines made by ABS Alaskan, Inc [5].

3 Companies and technologies

To find the companies that are established and emerging within this field, a web-based search was performed. Earlier written reports dealing with this subject were also reviewed. Especially a report about the technical status in 2006 made by Verdant Power [6] is used to list the present companies.

Table 3.1 gives a summary of the concepts that are in a commercial or pre-commercial stage today. Pre-commercial means that it has done a demonstration of a commercial size unit. Commercial means that there are units commercially available. No device on a laboratory or prototype stage is considered.

Companies and technology summary table											
Company	WCT Device Name	Turbine Type	Stage of Development	Min/Max Depth (m)	Min/Max Speed (m/s)	Axis of Rotation	Blade diameter	No. of Turbines per Unit	Ducted or Un-ducted	Anchor System	Unit Power Output
Thropton Energy Services (UK)	Water Current Turbine	Axis flow propeller	Commercial	Min 0.75	0.5/ depends on diameter	Horiz	4.0, 3.4, 2.8, 2.2, 1.8 m	One	Un-ducted	Pontoon, boat	Up to 2kW at 240v
Alternative Hydro Solutions Ltd (Canada)	Free-stream Darrieus Water Turbine	Cross-axis	Commercial	Min 0.6 for high speed stream	0.5/ depends on diameter	Vert	1.25, 1.5, 2.5, 3.0 m	One	Un-ducted	Customer determined	Up to 2-3kW
Energy Alliance (Russia)	Submerged Hydro Unit	Cross-axis	Commercial	0.5/ no limit	Min 3	Horiz	No data found	One	Ducted	Weighted base and cabled	1-5kW (and >10 kW)
New Energy (Canada)	EnCurrent Hydro Turbine	Cross-axis	Commercial	Min 2.5	Min 0.5/3 for max power	Vert	1.52 m	One	Un-ducted	Floating buoy with cables to anchors	5kW (and > 10kW)
Tidal Energy Pty. Ltd. (Australia)	TBD	Darrieus, Cross-axis	Pre-commercial	No data found	No data found	Vert	1.2 to 2.4	One	Ducted	Moored to the ground	Depends on velocity and size
Lucid Energy Technologies (USA)	Gorlov Helical Turbine	Helical Darrieus Cross-axis	Commercial	Vert: no limit. Horiz.: ~1.1	0.6/no limit	Either	No data found	One or more sections	Un-ducted	Various	Up to 20kW, depends on size
Seabell Int. Co., Ltd. (Japan)	STREAM	Dual, Cross-axis	Commercial	0.5/no limit	0.6/no limit	Vert	No data found	Two	Ducted	Floating buoy with cables to anchors	Undefined (small-scale)
Eclectic Energy Ltd. (UK)	DuoGen	Axial flow propeller	Commercial	0.5/no limit	1/5 (1.8 knots/9 knots)	Horiz	0.31 m	One	Un-ducted	Pontoon, boat	8 amps at 6 knots

Table 3.1: Companies and technology summary table

NOTE: Most of the information presented is gathered from the company's own websites or published literature without third party confirmation and should be evaluated in light of each design-developer's experience and track record of date.

3.2 Companies and concepts

As may be read from table 3.1, there are several companies with viable concepts within this field. In the following chapter, the companies and a short outline of their concepts will be presented.

3.2.1 Thropton Energy Services (UK)

Thropton Energy Services provide a complete range of services relevant to water current turbines from resource assessment to design and supply local manufacture. The company claims to have twenty years of experience in this field and have worked in UK, Sudan, Somalia, Egypt and Peru.

The company is the designer and manufacturer of the Garman turbine, which can be used for both water pumping and electricity generation. The turbine is axial and can be thought of as an underwater windmill which floats on a river or canal with the rotor completely submerged. It is moored in free stream to a post on one bank, making installation simple and cheap and minimising obstruction to river traffic. The propeller fan style turbine, available in diameters of 4.0, 3.4, 2.8, 2.2, and 1.8m drives an above-water generator.

The turbines are stand-alone units and have a maximum power output of about 2kW. To keep the capital cost down, Thropton has designed the turbine so that it can be locally manufactured. Garman turbines are being manufactured in Sudan, where they are used for pumping irrigation and drinking water from the Nile and for electricity generation. The systems are said to be easily deployed without heavy equipment, and thus they are suitable for use in developing countries.

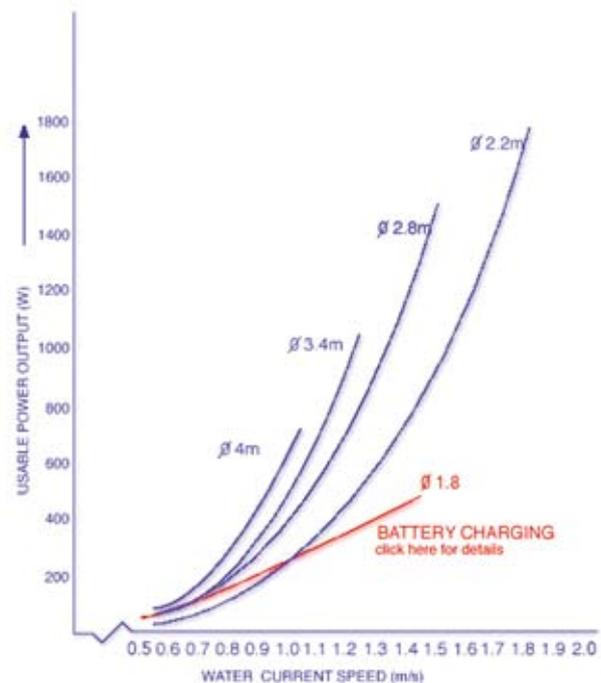
Minimum site requirements are a water current speed of at least 0.5m/s and a depth of 1.75m or more. [1]

Price per unit:

Available on request

Contact information:

Dr. B Sexon
Thropton Energy Services
Physic Lane, Thropton,
Northumberland NE65 7HU, United Kingdom
Tel: +44 1669 621288
E-mail: enqs@throptonenergy.co.uk
Web page: <http://www.throptonenergy.co.uk/>



3.2.2 Alternative Hydro Solutions Ltd. (Canada)

Alternative Hydro Solutions Ltd. has taken the Darrieus concepts and modified them to be more suitable for smaller rivers.

These small Darrieus turbines are, according to Alternative Hydro Solutions Ltd., constructed of high quality and durable materials. The turbine blades are made of aluminium with a solid cross-section in order to provide the required strength.

A number of electrical options are available depending on site requirements. These include a permanent magnet D.C. generator and a brushless alternator. The turbine is available in several diameters: 1.25 m, 1.5m, 2.5 m, 3.0 m, and 6.0 m, each available in custom lengths. [6]

The water flow speed that is generally accepted as the minimum for power production is 0.8 m/s [7]. The efficiency curves illustrated below indicates the power versus velocity for various combinations of diameter and height.

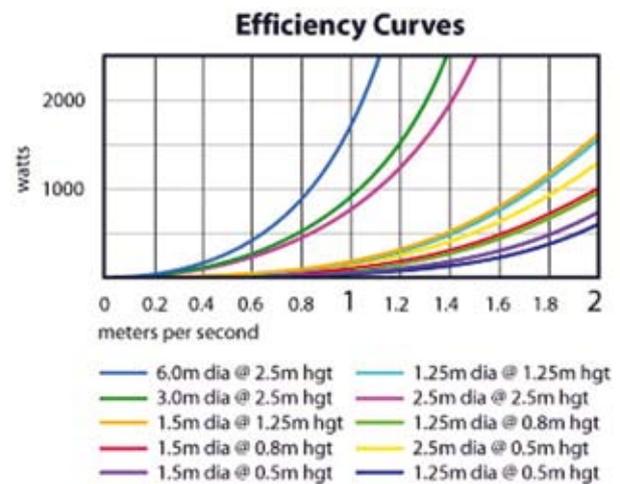
The company make several different sizes based on the customer needs. The 2m height by 3m diameter one has a cross sectional area of 6m^2 and will produce 750W at 1m/s. The turbine itself goes into a 2.5m by 2.5m by 0.5m box and assembles at site. It weighs about 200kg. If there was a known place some assembly could be done closer to site but this would only be of the bearing and shaft/ generator section.

Price per unit:

Depends on size. 750 W (at 1m/s): cen \$ 5000

Contact information:

Alternative Hydro Solutions Ltd.,
Suite 421, 323 Richmond Street East, Toronto,
Ontario, M5A 4S7, Canada
Tel: 416 368 5813
E-mail: sdgregory@alhydro.com
Web page: <http://www.alhydro.com/>



3.2.3 Energy Alliance (Russia)

Energy Alliance has a concept based on an in-plane, cross-axis turbine. A stream-flow having sufficient width, depth and velocities of about 3 m/s can be used for installation of the submerged turbine. At higher velocity, higher output can be obtained with the hydro-unit overall dimensions unchanged.

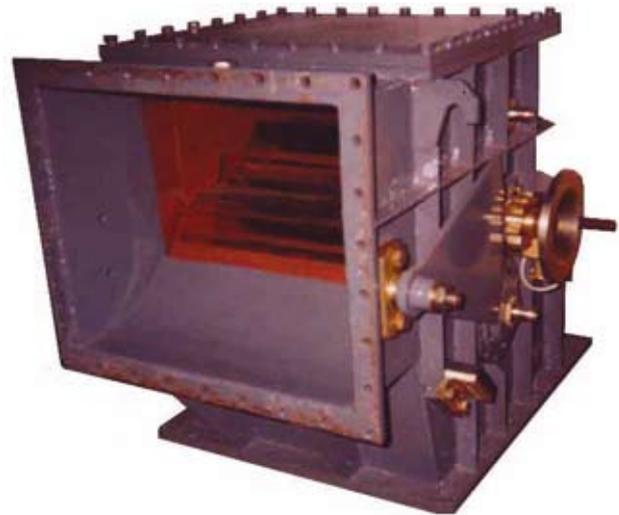
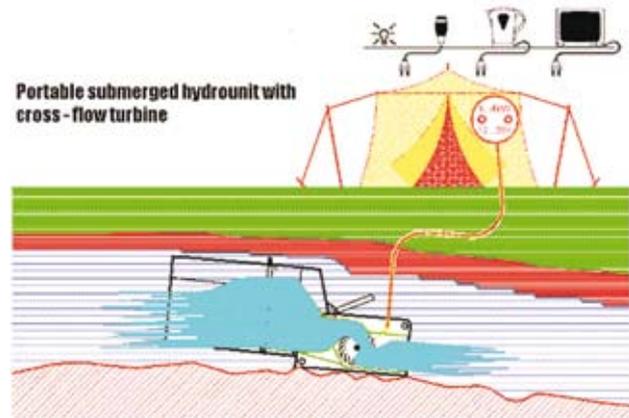
The turbine is housed in a duct that allows the system to be placed in a swift flowing river without the use of a dam. The units are expected to stay reliably secured by hydraulic and hydrodynamic forces. The submerged units can be operated year round, including the case when they are installed in the rivers with incomplete freezing of the river bed. The Energy Alliance plans to produce two versions of submerged hydro-units - portable units with outputs from 1 to 5 kW and stationary units with outputs from 10 kW to 225kW. The portable submerged hydro-units are intended for generation of 12V and 28V direct current, depending on the parameters of stream flow and generator type. [8] The turbines are currently in production [6].

Price per unit:

Tentative price for up to 16kW: 12800 USD
(Jan 2010)

Contact information:

Energy Alliance,
198095, St. Petersburg, Obvodny Kanal 122, Russia
Tel: 259-91-27 Fax: 113-02-07
E-mail: mail@energy-alliance.spb.ru
Web page:
<http://informal.ru/www.energy-alliance.spb.ru/sinke.htm>



3.2.4 New Energy Corporation Inc. (Canada)

New Energy Corporation Inc., with support from Natural Resources Canada and the CANMET Energy Technology Centre, have developed a series of turbine/generator sets that produce between 5 kW and 25 kW of power and are supposed to be used in rivers, irrigation canals, industrial outflows, and tidal estuaries. The EnCurrent generator is based on the vertical axis hydro turbine. It employs hydrofoils mounted parallel to a vertical shaft which drives a permanent magnet generator, with all electrical equipment mounted above the water surface. [9]

According to the website of the company, the 5 kW EnCurrent Power Generation System generates enough electricity to power two to five average homes on a continuous basis and is available in a standalone or grid connected configuration. The system is available in three models: A high velocity model (5 kW power output at 3 m/s), low velocity model (5 kW power output at 2.4 m/s) and restricted flow model. The restricted flow model uses a five bladed turbine which increases the resistance in the turbine. It is used in locations where the majority of the water in the channel flows through the turbine and where the increased resistance causes water to accumulate behind the turbine. [10]

ABS Alaskan delivers the EnCurrent systems. Every EnCurrent turbine is sold as a complete “water to wire” package, including appropriate inverters for the system type [11]. Overall system mass for a 5kW turbine is 340-360 kg and the height is 2.25 m. Shipping charges will be clarified by request, depending on how many devices that are ordered and where they are to be delivered. The economic payback for the system is promised to be as little as two years.

Price per unit:

For a 5kW turbine: 28000 USD (Jan 2010)

Contact information:

New Energy Corporation Inc.
3553 - 31 Street NW, Suite 473 Calgary,
Alberta, T2L 2K7, Canada
Tel: (403) 260-5240
Email: info@newenergycorp.ca
Webpage: <http://www.newenergycorp.ca>

Main supplier:

Abs Alaskan, Inc: www.absAK.com
Technical Product Questions: tech@absak.com
General Sales Questions: sales@absak.com
Shipping Questions: shipping@absak.com



3.2.5 Seabell International Co., Ltd. (Japan)

According to Seabell International Co website, The STREAM is the world's first invention of a «Dual axis turbine» (flat type, dual vertical axis), with an opposite rotation accelerating gear system and a system that reduces friction loss.

The current speed accelerates by taking in a large mass of natural non-head water current into the axel chamber. The smooth inflow/outflow design is supposed to minimize hydraulic head loss (friction) and capture energy efficiently.

The generator is mounted above the waterline, and this reduces manufacturing and maintenance costs. It is always suspended on the water surface, where the fastest current speed is, thus the largest concentration of energy exists in rivers and water ducts.

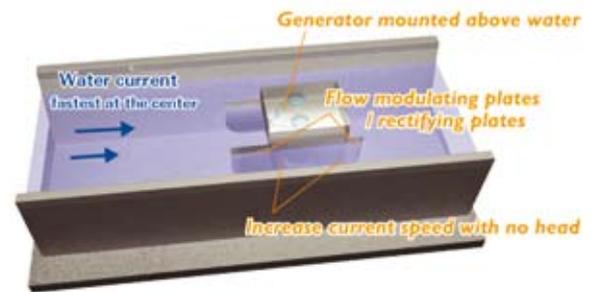
Employing dual axis structure taking into account flow behaviour of ducts, where the largest energy always exists at the centre. [12]

Price per unit:

Available on request

Contact information:

Seabell International Co
Mansan Building 2-8-11 Higashi-kanda, Chiyoda-ku,
Tokyo, Japan 101-0031
Tel: +81-35822-2275
Fax: +81-35822-2274
E-mail: info@seabell-i.com
Web page: <http://www.seabell-i.com/e/>



3.2.6 Lucid Energy Technologies (US)

Until 2007, GCK was the licensee of the Gorlov Helical Turbine (GHT) patents and technology. Then GCK Technology entered into a Joint Venture Agreement in March of 2007 to form Lucid Energy Technologies. All business relating to the GHT Technology is now being conducted through Lucid Seabell International Co [13].

GHT is a cross-axis turbine consisting of one or more long helical blades that run along an imaginary cylindrical surface of rotation like a screw thread. The design made by Alexander M. Gorlov developed at the North-eastern University, Boston, U.S.A has gained significant attention for both river and tidal applications [4]. Gorlov and co-workers in the United States tested models of the cross-flow turbine with helical blades and claim that its performance is superior to a conventional Darrieus cross flow turbine. The picture to the left shows two different examples of the concept.

The generated capacity is said to be proportional to the number of modules. In its vertical orientation the generator and gearing can easily be positioned above water. It starts producing power at approximately 0.60 m/s, according to studies done in 2004.[6]

According to Lucid, the Airfoil-shaped blades move at twice the speed of the current and the components can be assembled and replaced on-site. The aluminium construction is lightweight, rustproof, and recyclable.[13]

Price per unit:

Available on request

Contact information:

Lucid Energy Technologies 118 East Washington Street, Suite 2 Goshen, IN 46528, US

Tel: (574) 537-7300

E-mail: Unknown

Web page: <http://www.lucidenergy.com>



3.2.7 Tidal Energy Pty. Ltd. (Australia)

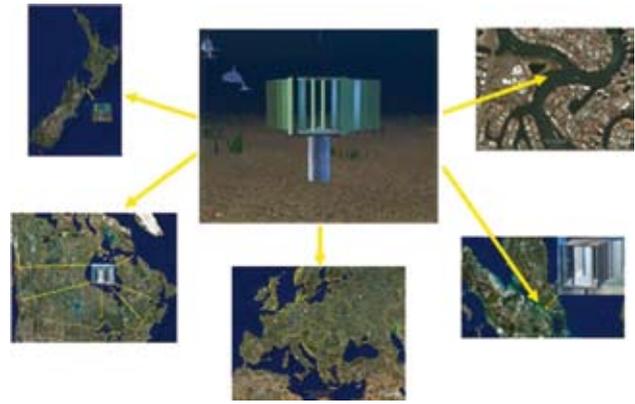
Tidal Energy is a company that was formed in 1998. Despite the fact that the scope of this report was to focus on applications in free-flowing rivers and not on tidal energy, the concept is considered because of the possible use in tidal streams like the Amazon River. According to the firm, flows around 2 m/s are ideal for electricity production with this turbine. The concept is pre-commercial, but Tidal Energy is offering demonstration turbines for sale or lease.[14]

Price per unit:

Capacity at 0.77-6.16 kW (1-2m/s): 35 000 AU\$
(Jan 2010)

Contact information:

Tidal Energy Pty. Ltd.
Bill Maywes, Australia
SKYPE. bmeywes (preferred)
Tel: +61 401 052 522.
E-mail: bill@tidalenergy.net.au
Web page: <http://www.tidalenergy.net.au>



3.2.8 Eclectic Energy Ltd. (UK)

The DuoGen is a combined water and wind mill. It is made to produce electricity to run most of the on-board equipment when sailing a yacht. Although this kind of technology is not in the scope of this report, it is considered because of the possibility of using it in a river or a stream.

The picture to the left shows when DuoGen is in its water mode. The DuoGen water mode is said to operate in a controlled fashion within the top 500mm of the water. This, coupled with the design of the three-bladed impeller, ensures that drag is minimised. [19] Several wind/water combinations are available on the market, but Eclectic Energy claim that they tend to be adaptations of single purpose machines and are characterised by being problematic to deploy and recover. DuoGen is supposed to be easy and efficient.

Price per unit:

Short Tower (1.3 metre): £1699.00 (including VAT)
Long Tower (1.6 metre): £1749.00 (including VAT)
Extra Long Tower (1.85 metre): £1849.00 (including VAT)
(Jan 2010)

Contact information:

Eclectic Energy Ltd. Edwinstowe
House High Street, Edwinstowe,
Nottinghamshire, NG21 9PR, United Kingdom
Tel: +44 1623 827829
E-mail: webmaster@eclectic-energy.co.uk
Web page: <http://www.eclectic-energy.co.uk/>



4 Research and experiences

The technology of small-scale hydro power is still in the stage of development and the possibilities are not yet fully explored. Small-scale hydro power has a growing interest around the world, and different concepts have been tried out with various outcomes.

As mentioned, the company Thropton Energy Service has twenty years of experience in the field of hydrokinetic turbines and have worked in UK, Sudan, Somalia, Egypt and Peru. They claim to have success in implementing their technology in remote areas and have done a case study where a farmer in Sudan got irrigation water for his 12 acre of land relying on their Garman turbine. The turbine replaced an earlier diesel engine powered system which required continuous supplies of fuel and oil which can be difficult to obtain in isolated areas. Eighteen months after the installation, the farm was visited by Thropton Energy Services staff. The turbine was working to the farmer's satisfaction and had at that time run for more than 11,000 hours without breakdown and without any spare part being fitted. [21]

At the web site of New Energy Corporation, a case study of a 5 kW EnCurrent Power Generation System is presented [22]. Electricity from the turbine started to flow into the micro-grid in Ruby, Alaska on August, 2008. Ruby is a community of approximately 200 residents located on the Yukon River in central Alaska. Electricity generation for the community is currently provided by diesel local tank farm, but the area has a large potential for hydrokinetic industry due to the high energy costs and abundant river and tidal resources. The system at Ruby has validated the concept of installing hydrokinetic turbines and producing power to micro-grids in Alaska. It is now being monitored for performance, grid integration, fisheries and navigation issues. These findings will then be used to further improve and perfect the hydrokinetic system. [22]

Another demonstration, with a Gorlov-type turbine was done in the Amazon, by a non-profit organization called IPAM, a Brazilian NGO. For the prototype at this site, it was expected that the energy produced would be sufficient to meet the basic needs of 10 households, at World Bank standards for rural electrification using solar energy. [18]

In order to capture the energy of the tides near the mouth of the Amazon River in Brazil, a prototype station was built, with characteristics adapted for small-scale generation of electricity in a rural area. The photograph shows a six-blade version of the



helical turbine used at the station. This turbine was built locally by a mechanic and a welder. The only outside components were the helical turbine blades themselves. [18] If this technology proves viable in the pilot phase, the organization expect that hundreds of small, tide-powered generating stations will be built near the mouth of the Amazon and elsewhere along the adjacent Atlantic coast. The organization claims that because the technology is accessible, affordable, and inherently small-scale, these stations can be built, owned, and operated by hundreds of rural residents. The people could use the energy for themselves and also offer battery charging service to their neighbours. The project started in 2006. The author has not been successful in providing a temporarily status report.

Information on several designs with horizontal and vertical axis rotors that were tested in the Amazon regions of Brazil could be found in [24]. The report summarizes the status of the use of small-scale hydrokinetic technology in the the region up to 2003. According to the report, the most successful experiences in the Brazilian area were done by a research group from the Department of Mechanical Engineering at the University of Brasilia. Several experiences with diverse prototypes of vertical and axial turbines were performed, as is further discussed in the paper Hydrokinetic Turbine for Isolated Villages [25]. The article conclude with that the hydrokinetic turbines presented in the paper are functioning, produce stable electrical energy at 220 volts and permits the use of domestic equipment. The developed technology proved to be robust and suitable for the extremely severe conditions of the remote and isolated villages, since it had been functioning uninterruptedly for seven years. The hydrokinetic power plant that was tested typically provided up to 2kW of electric power, depending on river characteristics. It was considered a reliable alternative for the electrification of isolated households and communities.

Research results on inclined axis turbines have been reported in the articles [26] and [27]. In these works, the feasibility of utilizing river energy in Bangladesh was studied, and conclusions were drawn in favour of

such technologies. The effects of varying blade pitch and shaft inclination angle were also studied and the average mechanical system efficiency was reported to be 30% [15].

The latter report, along with other research done in this field, is listed in the article River current energy conversion systems: Progress, prospects and challenges from 2007 [15]. The article may serve as a literature survey or technology review, and may provide better understanding of the issues and research interests in the field of water current technology. Some of the designs mentioned are patented technologies meant for large scale energy conversion, but much of the knowledge can also be used for small-scaled technology.

When doing literature search for this report, research results, experiments and case studies with well documented controls were hard to find. A website called International Small Hydro is a new site that is supposed to provide data for potential and developed small-scale hydro sites [17]. The site also describes the stages of planning that are required to determine if a site is technically and economically feasible. This can be a good source of information for future projects.

5 Discussion

Unlike conventional hydro and tidal barrage installations, water current turbines in open flow can generate power from flowing water with almost zero environmental impact, over a much wider range of sites than those available for conventional tidal power generation.

Small-scale hydropower is especially attractive as an alternative to highly polluting and costly diesel generation that provides electric energy in remote communities across the world. Since many remote communities are situated near moving water these turbines represent a promising source of clean power.

Most of the components, such as blade, generator, power converter, etc., needed for designing a turbine system are mostly readily available. Therefore, product development cycle, cost and level of technical sophistication are expected to be low. [15]

There are several advantages with this kind of technology compared to other small-scale power devices. As mentioned, it only takes a small amount of flow to generate electricity. It is reliable in the sense of that the water stream produces a continuous supply of

electrical energy in comparison to other small-scale renewable technologies. Also, the peak energy season is during the winter months when large quantities of electricity are required [2]. No reservoir is required and it is considered as a cost effective energy solution because of the low investment costs and maintenance fees. Water current turbines are therefore said to be an efficient and environmentally friendly technology for small-scale energy production. However, there are certain disadvantages that should be considered before constructing a small hydro power system.

First of all, in many locations stream size will fluctuate seasonally. During the summer months there will likely be less flow and therefore less power output. Advanced planning and research are needed to ensure that adequate energy requirements are met [2]. Another issue is that the power efficiency strongly depends on the location of the turbine. Suitable site characteristics are required, and their localization may be complicated and time consuming.

The ecological impact of small-scale hydro is minimal, however the locally environmental effects must be taken into consideration before construction begins [2]. Factors such as possible down-stream flow alterations and adversities on aquatic plants and animals should be brought into light [15].

These types of developments can bring about environmental and socio-economic benefits through integrated design, multipurpose planning and community involvement. [2] The turbines can replace earlier diesel engine powered systems which requires continuous supplies of fuel and oil. Due to the isolation of certain areas, obtaining fuel supplies is often a constant problem. The turbines could potentially provide several services such as water pumping for storage, livestock, human consumption, small industry, and irrigation. In such applications, water pumps could be employed instead of electrical generators, to facilitate direct mechanical energy conversion. [15] If the use of this technology in rural areas is to be a success however, the turbines must be easy to use and the quality must be reliable.

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