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Hydrokinetic turbines for power generation in Nigerian river basins

L. C. Eme[a,*], J. A. Ulasi[b], A. I. Alade Tunde[c] and A. C. Odunze[d]

[a] Civil Engineering Department, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria

[b] Electrical/Electronics Engineering Department, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria

[c] Electrical/Electronics Engineering Department, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

[d] Diamond International Education Centre, Suite D62 2nd Floor, EFAB Mall Annex, Area 11, Abuja, Garki, Nigeria

*E-mail: leeworks2002@yahoo.com

Abstract

This work presents a design for Hydrokinetic Renewable Energy (HRE), for off grid power generation for remote riverine regions in developing nations. The uniqueness of this technique for power generation using streams and other marine currents to generate electric energy is detailed. The problem of the impact of greenhouse gas emissions on the environment, rapid increase in human population, industries, modernization and our lifestyle put immense pressure on most power generation plants and infrastructures. Thus, global warming and carbon footprints of using fossil fuels to generate energy has driven the interest for energy generation from renewable sources. The Upper River Benue and Lower River Niger coastal basins, as well as the River Niger Basin on the Lower Niger sub-basin area of southeastern Nigeria was selected as a case study for the design of the hydrokinetic power generation technology. The results show that for a hydrokinetic turbine the level of power output is directly proportional to the flow velocity. Therefore the cost of its installation is reduced drastically from about $7,900 per installed kW to about $2,500 per kW, is easily assessable, less technical and a familiar motor technology for most of these communities. It is also a predictable form of energy in comparison to other emerging renewable energy fields like wind, solar and wave. Also this form of renewable energy is less harmful to the environment, has a lower noise emission and produces no greenhouse gases or any solid waste. HRE will bring energy security that is essential for the riverine dweller and curb rural urban migration and both improves the rural communities' standard of living and enhances their productivity.

Key words: horizontal, off-grid, renewable energy, vertical axis tidal

INTRODUCTION

The rapid increase in human population, industries and modernization of our lifestyle is putting immense pressure on most power generation plants and infrastructures. The impact of global warming and carbon footprints of other sources of energy has fueled further the clamour for energy generation from renewable source that are abundant across the globe. Renewable sources of energy, such as wind and solar, are well known, tested, and have established markets. However, other renewable technologies such as tidal fuel cells, which are still in development, show promise for meeting a portion of future electricity needs.

The rhythmic undulation of ocean waters around the world results in tidal forces. This is due to the gravitational and centrifugal forces between the earth, moon and sun. The gravitational force of the moon is 2.2 times larger than that of the sun, due to it nearness to earth (Gorji–Bandpy *et al.* 2013). As a result, the tide closely follows the moon during its rotation around the earth, creating diurnal tide and ebb cycles at any particular ocean surface.

Tidal energy is the energy dissipated by tidal movements; this can be harvested to create movement in a turbine to generate either mechanical energy or electrical energy. Tidal energy was first deployed on a large scale in 1967 in the La Rance tidal barrage in France. A tidal barrage utilizes the potential energy of the tide and has proven to be very successful, although many environmentalists expressed concern on its impact on aquatic life (Ghobadian *et al.* 2009).

Similarly, kinetic energy (water currents) in a flowing river can be harnessed to generate electricity; the use of water currents to turn a power turbine is often referred to as hydrokinetic generation (HK). This is the more desired method of capturing the energy, especially in riverine communities where other renewable methods such as a water dam for hydro or solar PV are considered expensive or difficult to implement (Acharya 2013).

The kinetic energy in the form of fast moving water passing through the turbines is converted into rotational kinetic energy by the blades of the turbine. The spinning turbine then drives the generator to produce electricity. Unlike wind and solar, water currents (ocean tide) are more predictable and they are observed to be steady over a wider period. Developing countries are in search of other sources of energy that are quick to deploy with relative operational ease. This technology seems to be ecologically suitable as well as economically feasible. The aim of this paper is to present an overview of the design of in-stream hydro energy and the potentials for off grid power generation for remote riverine communities in Nigeria.

METHODS

The technology of tidal barrages is known and has been proven effective, however it is subject to many constraints such as civil engineering work, the local environmental impact can be considerable, and there are limited suitable sites. This has greatly limited its use. An alternative way to harness the tidal current energy is to extract the kinetic energy from the free flowing water, in a similar fashion to wind energy conversion. This concept has dominated recent discussion in development of Tidal Energy Conversion (TED). Tidal streams are fast moving, and water is denser than air so there is a considerable impact force with the added advantage of easy cascading across depth, the local topography such as depth, headlands, inlets and between islands can magnify its effectiveness (Denny 2009). HK turbines are classified in several ways but one of the common classifications is the orientation of the most obvious design element; the rotor or rotor configurations. There are three main categories using this element: horizontal axis, reciprocating hydrofoil, and vertical axis, the blade types as shown in Figures 1 and 2 respectively. Another classification is possible based on their method of placement weighted to sit on the sea floor, or floating on water in a barge (usually land anchors are used to secure the barge to land or river/sea bed). Further classification is possible using the attachment ducts which is a way of concentrating the flows current from a larger amount of flowing water into a smaller rotor area, or non-ducted.

RESULTS AND DISCUSSION

Results and discussion involve hydrokinetic potential in Nigeria, the potential of the lower Niger river for hydrokinetic power generation, power production using HE energy in Nigeria, turbine selection and sizing and policy framework for renewable energy and rural development in Nigeria.

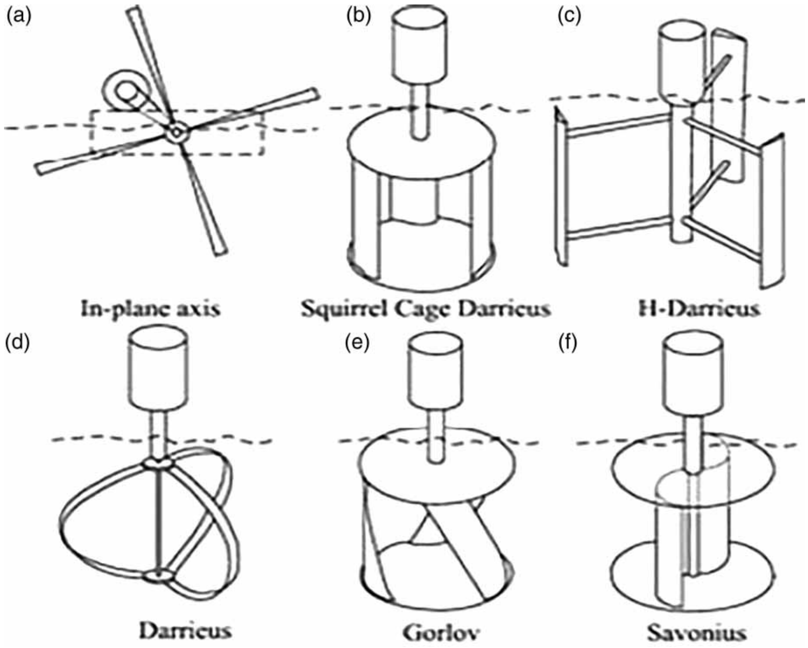

Figure 1 | Vertical or cross flow classification.

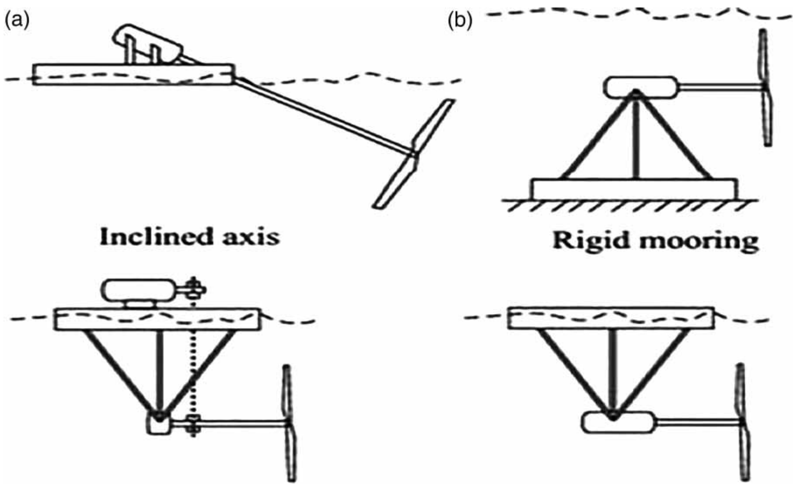

Figure 2 | Axial-flow (horizontal) turbines.

Hydrokinetic potential in Nigeria

The case study area being investigated is the River Niger basin with a focus on the lower Niger sub-basin area of southeastern and upper Benue. The River Niger is located between 5°N and 23°N of latitude, and 12°W and 17°E of longitude. It rises in Guinea Highlands and flows for a total length of about 4,100 km through Mali, Niger and Nigeria before reaching the Atlantic Ocean, see Figure 3(a). The Niger River basin is the largest trans-boundary basin in West Africa, and the second largest river in Africa by discharge volume (5,700 m^3/s; 1948–2006) after the Congo River (42,000 m^3/s) and is the third longest (4,100 km) (Olomoda 2012). About 44.2% of the basin area is located within Nigeria, see Figure 3(b).

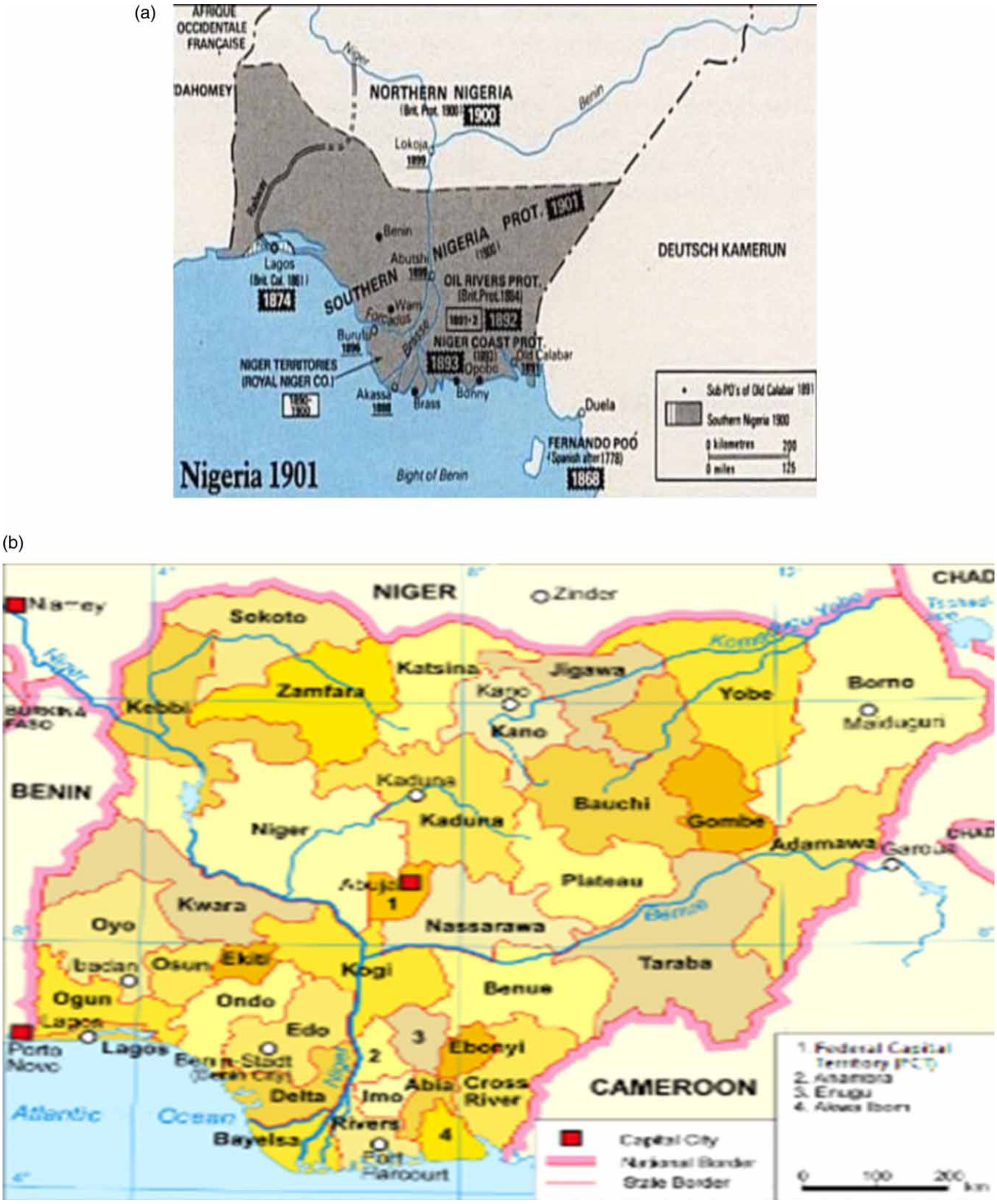

Figure 3 | (a) Map of nigeria showing tribute to the atlantic. (b) Map of nigeria showing rivers niger and states.

Potential of lower Niger river for hydrokinetic power genertion

It involves the flow rate of major rivers and flow duration in the upper and lower Niger.

Flow rate of major rivers

Olomoda 2012 estimated 5,500 m^3 annual water flow discharged into lower river Niger basin see Figure 4(a). Further, rainfall ranges from 700 mm in the north to 3,000 mm in the south. It flows into the lower Niger in Nigeria through other dams. River Benue is the biggest tributary of the Niger River. It forms a confluence with it at Lokoja in Nigeria; River Benue also contributes the highest flood flow to River Niger in a short duration with a minimum flow rate of about 600 m^2/s (Olomoda 2012) With a flow rate of more than 13 cubic meters of water per second there is an upstream head of 0.3 m along the tributary of the Niger.

Flow durations in the upper and lower Niger

Lokoja gauge station data shows a minimum steady flow rate of over 2,000 m^3/s during the dry season of about five months and above this threshold for another seven months (Olomoda 2012); see Figure 4(b) and Table 1.

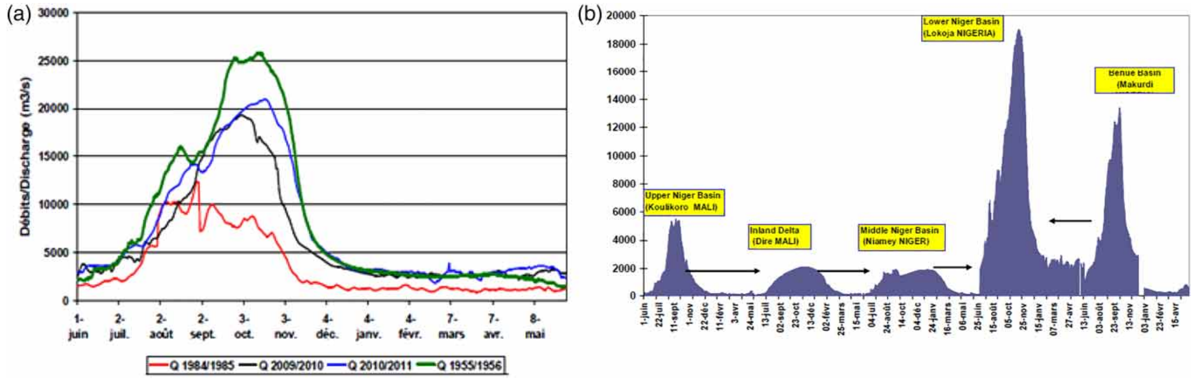

Figure 4 | (a) Comparative hydrograph of river Niger in the lower Niger basin of lokoja and (b) Hydrograph showing the river Niger daily flow characteristics.

Table 1 | Lower Niger river flow rate variation more than 25 years

S/N	Station	River	Period	Q_{mean} (m^3/s)	Q_{max} (m^3/s)	Year	M_{ind} (m^3/s)	Year
1	Lokoja	Niger	1982–2003 1960–1981	68,936.5 58,646.9	94,790 (1960–2003)	1969	25,760	2003
2	Onitsha	Niger	1960–1981 1982–2003	71,136.64 59,721.1	87,810 (1960–2003)	1999	25,760	2003
3	Makurdi	Benue	1960–1981 1982–2000	41,369.21 34,660.84	61,869 (1960–2000)	1969	20,378	1983

Power production using HK energy in Nigeria

Friction is the major detriment to water velocity. The lesser the water contact to the ground the higher the water current speed. The width and depth of the river, the contour of the river bottom, depth of the turbine rotor, cross-sectional area, and the roughness of the river bottom are identified as key parameters in the turbine placement (ABS Alaskan Inc n.d.) For a site to be seen as good for the hydrokinetic power generation deployment of any type of HK turbine it is important to consider the following factors:

Water depth

The total length of the Lower River Niger, which is undergoing dredging between Lokoja and Warri, measures over about 575 km. The river's strong meandering character will be corrected, with a minimum depth of 2.5 meters and curve radiuses are to measure a minimum of 600 meters. Each kilometer of the alignment shall only include one change in direction, with regulating measures to guide the flow. The channel shall be a minimum 60 meters wide with a minimum depth of 2.5 m, although the river water level may vary up to nine meters between the dry season and the rainy season (Burg 2010).

Water velocity

The best performance and the highest power production are made by a smooth linear flow of water at high velocity (ABS Alaskan Inc n.d.). The flow of a river stream has stochastic variation features, which can be both seasonal and daily. The placement of the water current turbine must optimize these features. For a hydrokinetic turbine, the level of power output is directly related to flow velocity. The acceptable velocity of water current required according to the literature and several manufacturer specifications is typically between 103 m/s and 4.06 m/s. Optimal currents are in the range of 3.0 m/s to 4.0 m/s (ACEP 2011).

Water debris content

Dredging for sand is a major trade activity of most riverine communities along the lower River Niger. In the upper area of the river, along Benue Lokoja axis, the majority of industry is agrarian, thus limiting the debris deposit pollution to mostly degradable materials.

Anchoring mechanism

Although there has been little work done to ascertain a River Niger bed soil profile in Nigeria, Youdeowei & Nwankwoala 2011 shows that sand may be derived at minimum depths of about 1.0 m–7.0 m at the sample axis of the river. Medium to coarse grained, poorly graded (well-sorted) sands, which display uniform size gradation in the sand range, were encountered below the riverbed in all the locations. The relative stability of the coarse sand will be a sufficient support for two pole-mounted hydrokinetic turbine structures within the lower Niger region. These support structures can also serve as cable or power distribution cable support to land (substation).

Settlement along the river banks and those living inland of the lower Niger can benefit immensely from hydrokinetic power generation. Their means of living, including food, income, and assets will be enhanced and living conditions improved considerable. Secondly, there are competing users of the water stream, e.g. small boats, fishing vessels, bridges, etc., and these might reduce the effective usable area for a turbine installation and limits installation of the turbine to a side of the river bank to make room for other users.

Turbine selection and sizing

System load

The priority is to always meet customer load 24 hours per day. The system will prioritize the dispatch of energy to maximize revenue in the day and optimize service delivery to rural dwellers at night. The daytime energy generation will serve the community's commercial ventures such as produce cold rooms, agricultural industries or businesses and other purposes such as making ice, pumping water and commercial cell phone charging kiosks.

Load profiles

To guide the system design, four different load profiles were used to model the anticipated loads in a typical village as shown in the bar charts in Figure 5. First, (a) 'Basic' load profile for 40 households,

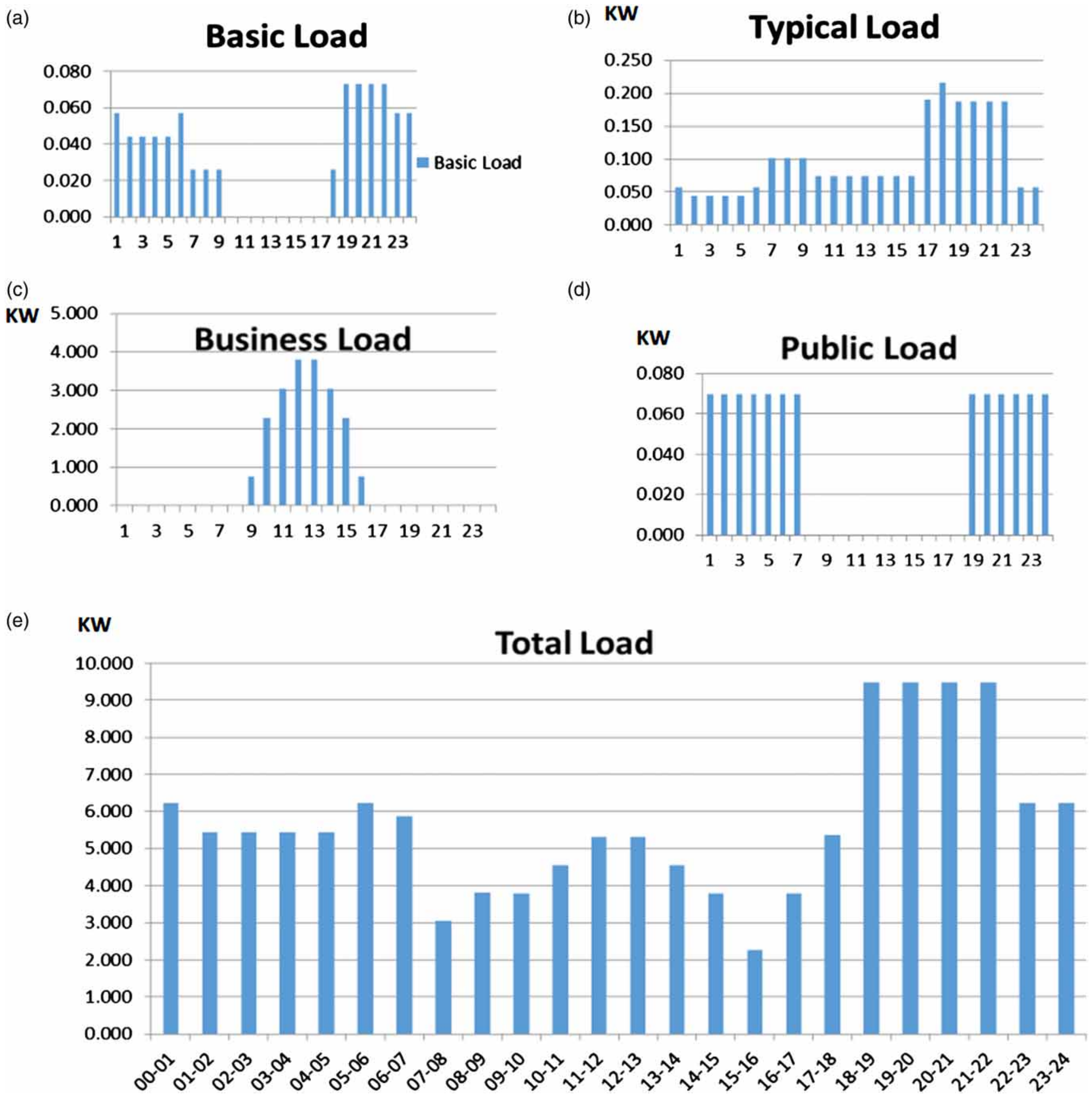

Figure 5 | Hourly load variation modelling for typical rural communities.

which provides for only a small amount of lighting and fan plus overnight cellphone charging. Second (b) 'Typical' load profile for additional 20 customers provides for much more enhanced loads including several fans, lights, a television and radio. Thirdly, (c) is the 'Business' load profile as it fluctuates in the rural communities; and fourthly, (d) is the 'Public' load profile as it remains constant.

Service levels

The basic nominal power per customer is a single four-way distribution box with a total available power of 0.5 kVA protected by a 2A breaker. A higher power service for home customers and businesses is at the discretion of the owner/operator.

Times of service

A multi-tier rate tariff is recommended to incentivize the use of daytime HT-generated power, compensate for cheaper home power and dis-incentivize overnight power consumption by heavy users.

Power for shared services such as street lighting, ice making or water pumping will be at the discretion of the owner/operator and at the government-subsidized rate.

Energy usages

The average estimated (non-peak) total system-wide power consumption is at least 9.5 kVA per day. Peak customer load is estimated at 0.5 kVA with a typical overnight load of not more than 0.1 kVA. This projection is based on 20–40 households.

HT selection

The relationship of power Pt shows that power energy capture is highly dependent on velocity and the surface area of the blade. It increases exponentially with current speed. (Mangold 2012, Sørnes 2010 and Khalid *et al.* 2013) provide various available hydrokinetic turbines and blade options in today's market. For low head & shallow depth, VATT is a better option. VATT is more sensitive to cavitation, because it's working principle is based on lift type design (Bahaj *et al.* 2007). The projected water velocity from several flow stations in Table 2 is well over the optimum velocity required to generate electricity by most HK turbines. Velocity energy per station for hydro volts avionics is as shown in Figures 6 and 7. Therefore, a medium range 20 kw to 45 kw is deemed suitable for these areas.

Table 2 | Spot lower Niger river flow rate and velocities at 2.5 m shallow and 9 m deep points

s/n	Station	River	Q_{mean} (m^3/s)	V_{mean} m/s	Q_{max} (m^3/s)	V_{max} m/s	Q_{min} (m^3/s)	V_{min} (m/s)	Depth (m) D_{max}/D_{min}	Cross Sec Area Amin
1	Lokoja	Niger	68,936.5 58,646.9	12.77 10.86	94,790 Shallow	17.55 52.66	25,760	4.77 14.31	9 2.5	5,400 1,800
2	Onitsha	Niger	71,136.6 59,721.1	13.17 11.06	87,810 Shallow	16.26 48.78	25,760	4.77 14.31	9 2.5	5,400 1,800
3	Makurdi	Benue	41,369.2 34,660.8	7.66 6.42	61,869 Shallow	11.46 34.37	20,378	3.77 11.32	9 2.5	5,400 1,800

Policy frame work for renewable energy and rural development in Nigeria

The Federal Government of Nigeria (FGN) passed the Electric Power Sector Reform Act 2005, and provides the legal footing for the establishment of the Rural Electrification Agency (REA), a governmental body charged with designing and implementing strategies to achieve rural access to electricity in Nigeria. The REA initiative yielded marginal results with fewer than 20% of rural households having access to electricity, which is lower than when the REP commenced. The growth in demand for electricity has outpaced supply and population growth. This has driven the rate of new household formation higher than the rate of new connections. As a result, rural households still rely on fuel wood and other expensive, unhealthy and unsustainable sources of energy (Econ One Research Inc. *et al.* 2006).

To stem this trend, the following incentives were provided to facilitates and encouraged generation of power from renewable sources.

i. Improve service standards, including increased availability, reliability and quality of power supply
ii. Improve affordability of power through competitive alternative and renewable energy, subsidies on capital investments and reduced barriers to entry, etc.

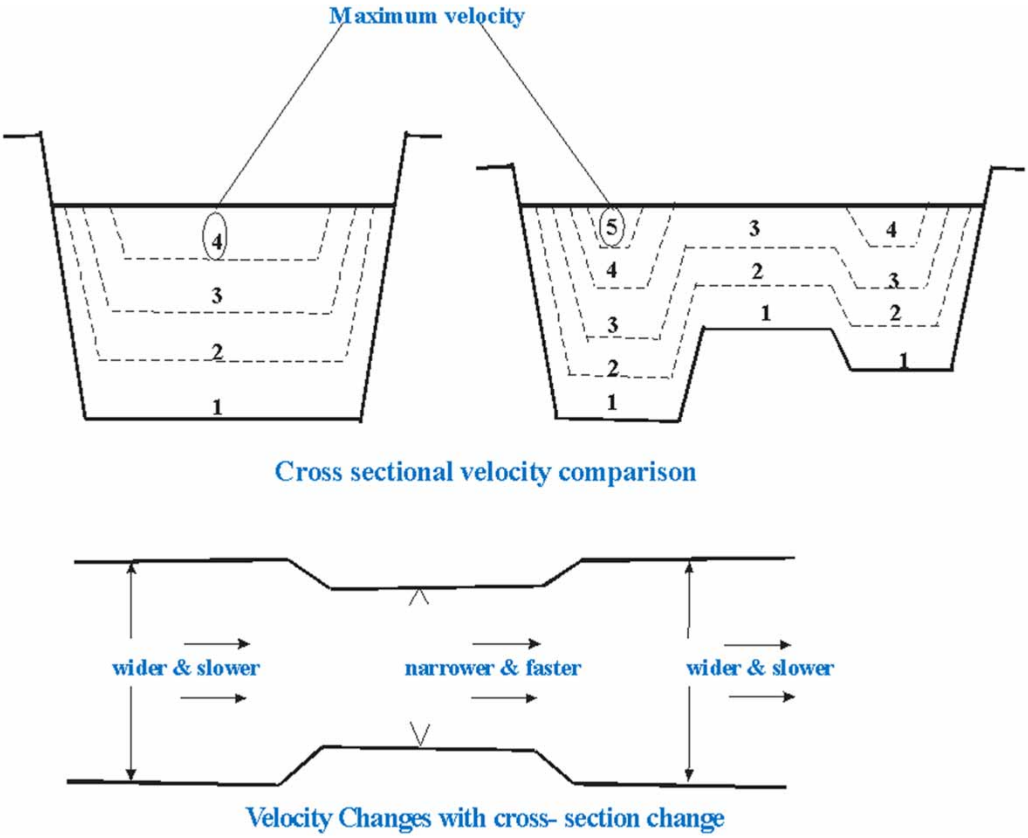

Figure 6 | Hydrokinetic turbine placement factors (ABS Alaskan Inc. n.d.).

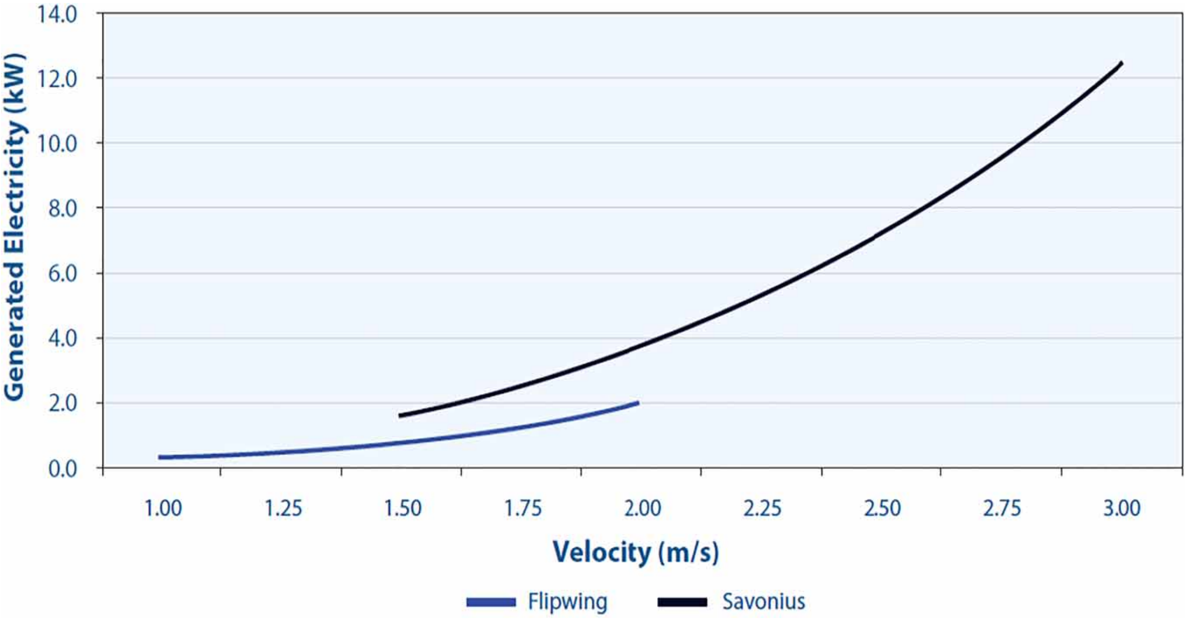

Figure 7 | Power generation of C-12 output at different velocities (kW) (hydrovolts 2013).

iii. Improve financial sustainability of power supply, through appropriate tariffs policies that reflect costs of operation, maintenance, system compensation, expansion and upgrade and a reasonable return on investment.
iv. Improve an information database to facilitate effective planning and efficient rural coverage.

CONCLUSION

The cost of its installation has reduced drastically from about $7,900 per installed kW to about $2,500 per kW (Johnson & Pride 2010). Easily assessable, less technical and a familiar motor technology to most of these communities, it is a predictable form of energy in comparison to other emerging renewable energy fields like wind, solar and wave. Also this form of renewable energy is less harmful to the environment, less noisy and produces no greenhouse gases or any solid waste. The even distribution of viable waterway hydrokinetic technology will bring energy security that is essential for the riverine communities, will help curb rural urban migration and improves the rural comminutes' standard of living and productivity.

Most importantly, hydrokinetics turbine has little or no recurrent cost such as: logistics and fuel sourcing for island distribution generators that are prone to various challenges such as weather, poor road infrastructure, etc. Its deployment will go a long way towards resolving power issues in most riverine communities that are difficult to reach and not economical to connect to the national grid, where a decentralized solution would be appropriate.

REFERENCES

ABS Alaskan, Inc. n.d. *Siting Considerations For Kinetic (In-Stream) Hydro Turbines*.

ACEP 2011 *Hydrokinetic Energy (In-River, Tidal, and Ocean Current)*.

Acharya, S. 2013 *Renewable Energy Revolution*. [Online] Available at: www.sunilacharya.wordpress.com. [Accessed 5th may 2016].

Bahaj, A. S., Molland, A. F., Chaplin, J. R. & Batten, W. M. J. 2007 Power and thrust measurement of marine turbines under various hydrodynamic flow conditions in cavitations tunnel and a towing tank. *Renewable Energy* **32**(3), 407–426.

Batten, W. M. J., Bahaj, A. S., Molland, A. F. & Chaplin, J. R. 2008 The prediction of the hydrodynamic performance of marine current turbines. *Renewable Energy* **33**(5), 1085–1096.

Burg, T. v. d. 2010 Dredging for development on the lower river Niger between Baro and Warri, Nigeria. *Terra et Aqua* **121**, 27–30.

Denny, E. 2009 The economics of tidal energy. *Energy Policy* **37**, 1914–1924.

Econ One Research, Inc. 2006 *Rural Electrification Strategy and Implementation Plan of the Federal Republic of Nigeria*. Bureau of Public Enterprises, Abuja.

Ghobadian, B., Najafi, G., Rahimi, H. & Yusaf, T. F. 2009 Future of renewable energies in Iran. *Renewable And Sustainable Energy Reviews* **13**, 689–695.

Gorji-Bandpy, M., Azimi, M. & Jouya, M. 2013 Tidal energy and main resources in the Persian gulf. *Distributed Generation and Alternative Energy Journal* **28**(2), 61–72.

hydrovolts 2013 www.hydrovolts.com. [Online] Available at: www.hydrovolts.com/Hydrovolts_C-12-Canal-Turbine.pdf [Accessed 13 May 2016].

Johnson, J. B. & Pride, D. J. 2010 *River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska*. The Alaska Center for Energy and Power, Alaska.

Khalid, S. S., Liang, Z. & Shah, N. 2013 Harnessing tidal energy using vertical axis tidal turbine. *Research Journal of Applied Sciences, Engineering and Technology* **5**(1), 239–252.

Mangold, E. 2012 *Hydrokinetic Power:An Analysis Of Its Performance And Potential In The Roza And Kittitas Canals*. s.l.: Environmental Studies Evergreen State College.

Olomoda 2012 Challenges of Continued River Niger Low Flow into Nigeria. In: *Hydrology for Disaster Management*. Issue Special Publication of the Nigerian Association of Hydrological Sciences, pp. 145–155.

Sørnes, K. 2010 *Small-scale Water Current Turbines for River Applications*. ZERO – Zero Emission Resoruce Organisation, Maridalsveien 10 0178 Oslo.

Youdeowei, P. O. & Nwankwoala, H. O. 2011 Studies on sub-soil characteristics of sand deposits in some parts of Bayelsa State, Eastern Niger Delta, Nigeria. *Journal of Soil Science and Environmental Management* **2**(2), 34–38.