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HYDROKINETIC ENERGY CONVERSION SYSTEMS: PROSPECTS AND CHALLENGES IN NIGERIAN HYDROLOGICAL SETTING

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Abstract
Hydrokinetic energy conversion systems utilize the kinetic energy of flowing water bodies with little or no head to generate other useable forms of energy. In the last few years various research and development efforts have been made to bring out this technology from the proof of concept stage and to demonstrate its technical feasibility and potential to be deployed for the supply of stand- alone/off-grid electric power production. Being also a variant of the small hydropower scheme, which are usually site specific, much of the studies done on the technology are suited to specific sites and the peculiar hydrology of those localities. This paper, thus, explores this new emerging technology and its prospects, potentials, challenges and frameworks for its adaptation in Nigerian hydrological setting.

Keywords: Hydrokinetic, Small hydropower, Hydrology, Turbines, Adaptation

1. Introduction:

Energy stakeholders today agree that renewable energy technology can be successfully utilized to cover the increasing gap between energy needs and its sustainable, available and affordable supply and to ensure less polluted reduced environment [1], [2], [3], [4], [5] and [6]. Hydropower and wind power seem to be the optimum choices among the renewable [7]. Conventional hydropower, with its use of dams and impoundments, harness the potential energy stored in reservoirs by creating a hydraulic head differential which is eventually converted into electrical energy through suitable turbo machinery. However an emerging class of hydro-to-electric power system, which is being strongly recognized as a unique and unconventional renewable energy solution, is the marine and hydrokinetic energy conversion technology [8]. Hydrokinetic (In Stream, or water current) energy conversion implies the utilization of the kinetic energy of rivers, streams, tidal currents or other man-made waterways for generation of electricity. It is a class of "zero head" hydropower which extracts energy from the velocity of flowing water to drive a generator. It can also be defined it as low pressure run-of-the-river ultra-low-head turbine that will operate on the equivalent of less than 0.2m of head [9]. It does not involve any construction that alters the natural pathway of moving water and is more environmentally friendly.

Its principle of operation is analogous to that of wind turbines, though they capture energy through the process of hydrodynamic, rather than aerodynamic, lift or drag. This new technology is seen as a special and unorthodox solution for power generation that falls within the category of in-land water resource and marine energy [10].

Much has been said on the need to include and increase renewable energy technologies in Nigeria's energy mix [11], [12], [13] and [14]. Blessed with a network of rivers, streams, coastal/tidal and ocean currents together with artificial water channels and other water bodies, Nigeria's hydrological setting shows considerable hydro potential both at the larger scale (megawatts) and the smaller scale (Kilowatts). Already 32% of the total installed commercial electric power capacity is from hydropower [15]. However, apart from the small hydro projects which involve dams, the various flowing rivers and streams crisscrossing the length and breadth of the country could be used for the deploying of hydrokinetic energy conversion technology for the generation of electric power for rural/off grid areas and for augmenting the production of existing conventional dam hydropower plants. This article looks at the possibilities of such and the challenges of its adaptation.

2. Hydrokinetic Energy Conversion Technology

2.1 Hydrokinetic Energy Conversion System

Hydrokinetic energy conversion systems has been described as electromechanical energy converters that can be deployed not only to convert wave energy and marine currents in oceans, but also natural streams like rivers, tidal estuaries, as well as in some constructed waterways [8][16]. The available power that can be extracted from a hydrokinetic system is a function of the density of the water, the cross sectional area of the flowing water channel or the turbine and the speed of the water current. The minimum velocity of water current required according to the literature is typically between $1.03ms^{-1}$ and $2.06ms^{-1}$. Optimum currents are in the range of $2.57ms^{-1}$ to $3.6ms^{-1}$ [17].

Power from a hydrokinetic devise from [53] can be expressed as:

$$\frac{1}{2}\rho A \cup_o{}^3 \eta Cp \qquad (1)$$

In (1), ρ is the mass density in kgm^{-3} , A is the swept area of the rotor blade in m, $\cup_o{}^3$ is the velocity of the fluid (cubed) in ms^{-1}, η is the efficiency of the generator and Cp is the power coefficient.

2.2 Terminology of Hydrokinetic Energy Conversion Systems

The name hydrokinetic is interchangeable with similar terms used for related technologies in the literature. It is referred to it as River Current Energy Conversion System (RCECS) [8]; it is also called Marine Hydrokinetic devices (MHK) [54]; Water Current Turbines (WCT) [18], [19] and [20], Ultra-Low-head Hydro Turbine(ULHHT) [9] ; In-stream Hydro Turbine (ISHT) and River In-stream Energy Converter (RISEC) [21] and Zero Head Hydro Turbine (ZHHT) [22]. For this work it shall be called 'hydrokinetic', as this covers a broader range of river current/tidal schemes.

2.3 Schemes of Hydrokinetic Energy Conversion Technology

There are quite a number of hydrokinetic energy conversion systems that utilize some other schemes to harness the energy in a fluid stream apart from the use of turbines. The non-turbine systems are: Flutter vane, Piezoelectric, Vortex Induced Vibration, Oscillating hydrofoil and Sails [10] [16]. The turbine system types are: Axial, Vertical axis, Cross-flow, Venturi and Gravitational Vortex [23]. At the moment, only the turbine model is considered technically feasible while the non – turbine systems are largely still at proof-of- concept stage.

2.4 Hydrokinetic Energy Turbine Systems

A typical hydrokinetic turbine system may contain a variety of components like the turbine rotor, the gearing/drive train, the power converter, control instruments and protection devices, channel augmentation, mounting, mooring etc [7], [10], [8]. A sketch of the vertical axis Darrieus turbine system is presented in Figure 1 showing some of the features.

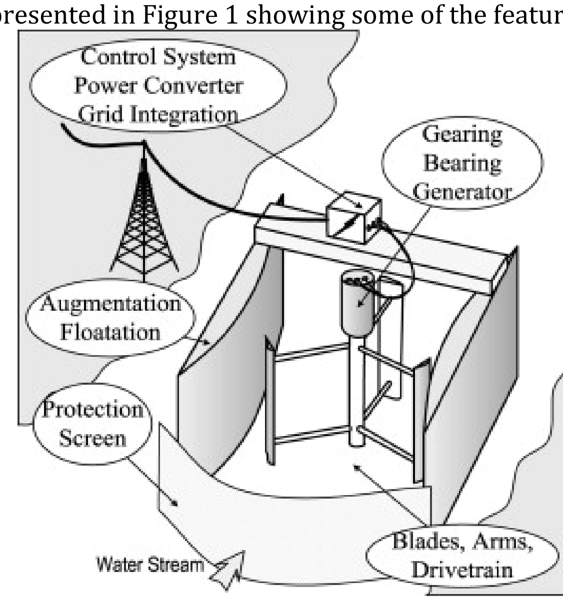


Figure 1: Sketch of a typical Hydrokinetic Turbine System (Source: [8])

Hydrokinetic turbine rotors are of different designs based on the prototypes of some hydro companies. Classification is presented in Figure 2.

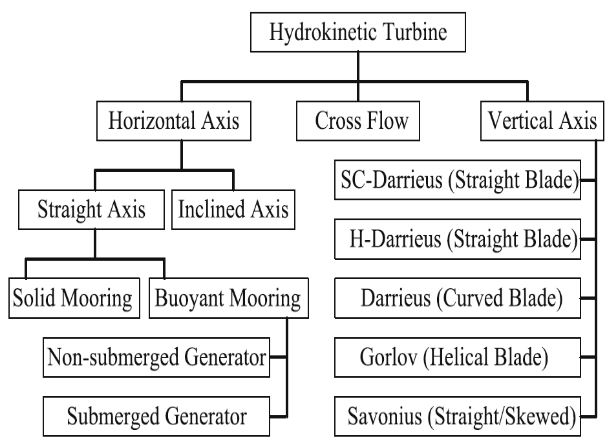


Figure 2: Classification of hydrokinetic turbines (Source: [8]).

The classification was made by considering the placement of the rotor axis with respect to the direction of water flow.

(i) Horizontal axis (comprising of straight and inclined axis)
(ii) Cross flow

(iii) Vertical axis

The axial flow (horizontal axis) turbines has been described as the class of hydrokinetic rotors that have axes parallel to the fluid flow and utilize propeller type rotors [24], [18], [10]. They employ the lift and drag type blades. They find their choice of use in the extraction of ocean energy and are expensive for small power applications. Some of the inclined axis types have been commercialized. The cross flow turbines have rotor axes in orthogonal position to the flow of water but parallel to the water surface. They also employ lift and drag blades. They are interesting alternatives when one has enough water, defined power needs and low investment possibilities e.g. off grid electrification [25]. The last class is that of the Vertical axis. These have their axes orthogonal to the water flow and vertical to the water surface. Examples are Gorlov, Darrieus and Savonius turbines. Figures 3 and 4 show some of the types of horizontal and vertical axis hydrokinetic rotors.

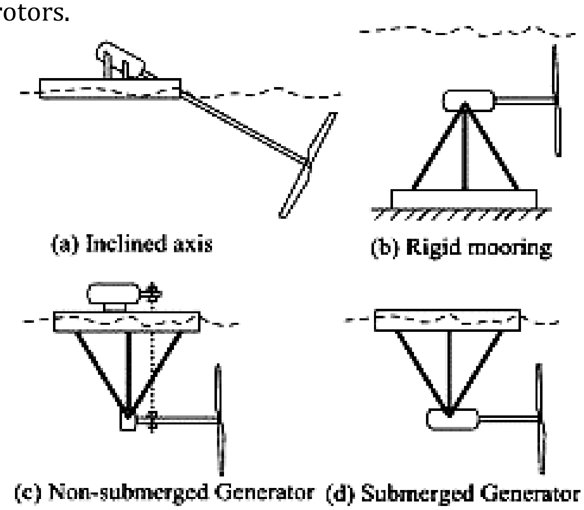


Figure 3: Axial (horizontal axis) hydrokinetic rotors (Source: [10]).

3. Global Outlook of Research, Development and Commercialization Efforts of Hydrokinetic Energy Conversion Technologies

Since the early 1960s world hydroelectric generation has steadily risen, globally, by an average of 3% annually. In 2011, hydropower supplies over 15% of the total energy generated globally and are represented in over 100 countries. The trend of hydroelectric generation is shown in Figure 5.

As the usage of renewable energy technologies (and particularly hydropower) is expected to continue to rise in the next few decades, marine and hydrokinetic technology is expected to play a key role. In Figure 6, the contribution to global energy generation in the coming years is projected [7].

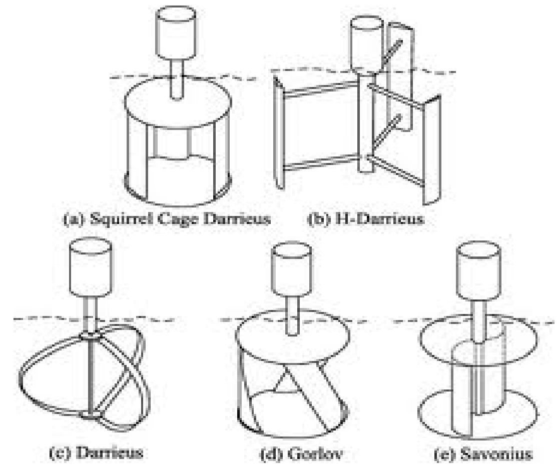


Figure 4: Vertical axis hydrokinetic rotors (Source: [10]).

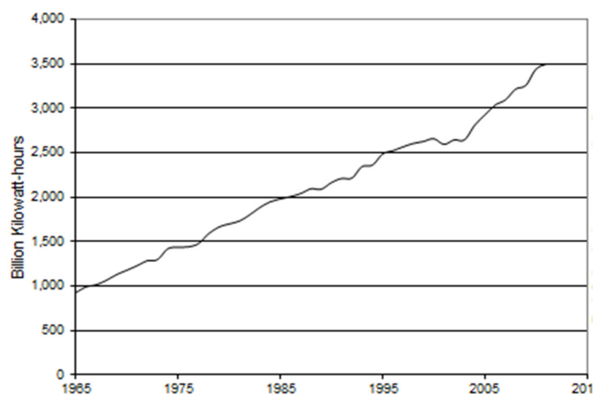


Figure 5: Trend of World Hydroelectric Generation from 1965-2011 (Source: [26])

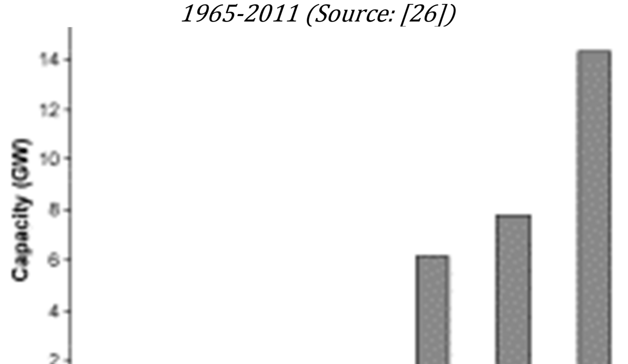


Figure 6: Hydrokinetic Energy Capacity Forecast 2009 – 2015 (Source: [7])

Chart of the projected contributions of the various technologies (wave, tidal, river hydrokinetic etc.) involved in hydrokinetic energy generation, up till year 2015, is presented in figure 7. Power from tidal currents is expected to dominate the hydrokinetic industry, however, river current hydrokinetic energy with its advantage of off grid power generation also holds promise, particularly for countries with better tidal and river current potentials and developing regions of the world.

Various developed/developing nations, regions and organizations have been working on a variety of ways of adapting this technology (modeling, developing prototypes and some to the level of commercialization of this technology).

Alaska, together with some other parts of USA and Canada, have been much involved in resource assessment and technology development through their universities (Universities of Washington, Manitoba, Tennessee etc.) research centres, (e.g. the Electric Power Research Institute, Alaska Hydrokinetic Research Centre etc.) government agencies (National Renewable Energy Laboratory, US Department of Energy, National Research Council of Canada etc.) and through private corporations (Hydrovolts, New Energy Corporation etc.) [27], [17], [28], [29], [30] and [31].

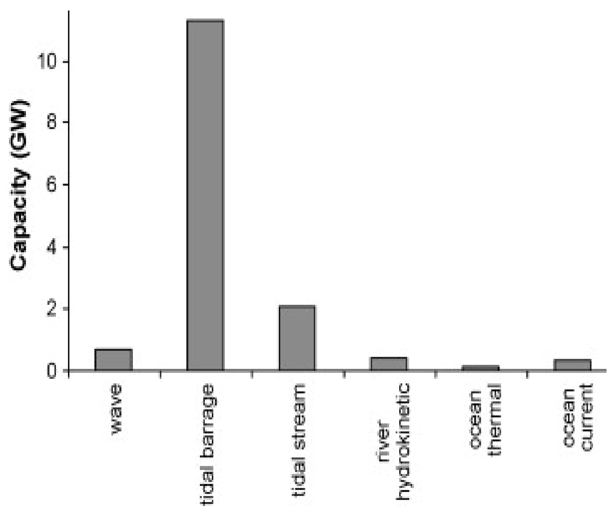
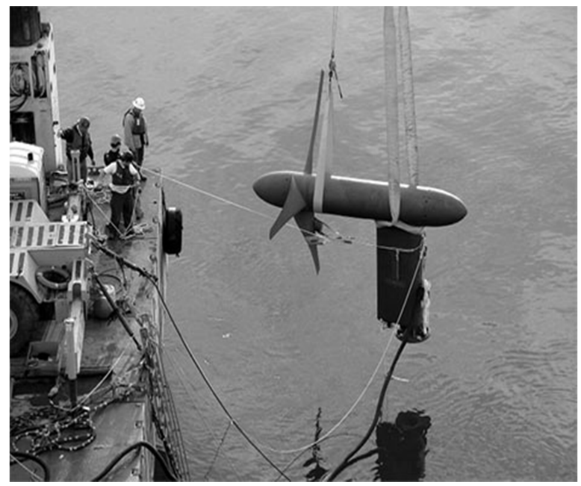


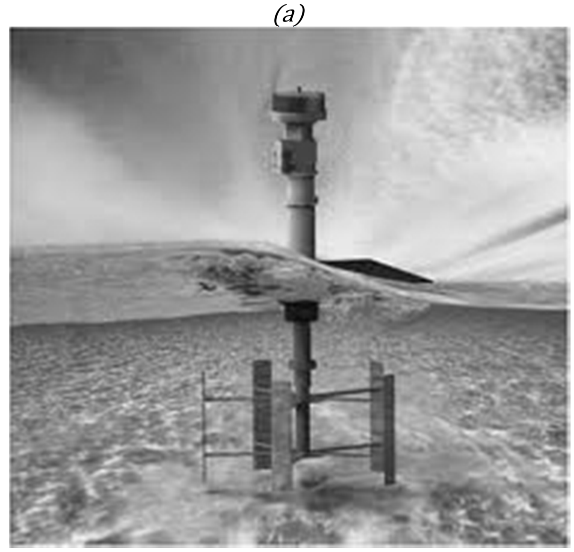
Figure 7: Projected Contributions of various Hydrokinetic Technologies by 2015 (Source: [7])

The Electric Power Research Institute (EPRI) recently completed a mapping and assessment of hydrokinetic resources in rivers of the continental United States and found that these undeveloped resources could provide 3 percent of the nation's annual use of electricity [32]. Verdant Power Canada developed a 3-bladed axial flow turbine rated 35kW and called it Kinetic Hydropower System (KHPS). In 2003, the organization tested a 3m prototype model in the East River in New York City and generated 15.5 kW at 2.13 m/s, yielding efficiency (Cp) of 43% [20]. New Energy Corporation developed the EnCurrent Hydro Turbine, which is a vertical axis Darrieus type turbine and which is able to produce 25 kW and operate in water velocities of 1.5 to 3.0 m/s [30]. 25 kW is sufficient to provide power to 20 or 50 North American or European homes [33]. The turbines can be installed in rivers, irrigation canals, the industrial effluents, and even the tides and can range in size from about 3 kW to over 1 MW. Figure 8 shows some of the turbines which have been developed.

In Brazil, South America, [34] demonstrated the generation of AC power directly using small axial flow and cross flow turbines. Using ducts, the system was able to power a remote medical post in the state of Bahia. Likewise in Argentina some laboratory tests were carried out using channeling device on a vertical axis turbine [19]. The tests were able to improve the power output.



(a)



(b)

Figure 8: Examples of Hydrokinetic Turbines being developed. (a) Verdant Power's Kinetic Hydropower System (KHS) and (b) New Energy Corporation's EnCurrent Hydro turbine

In South Australia, [35] reported some developments and tests conducted on ducted (diffuser augmented) water current turbines and highlighted their advantages

In Taiwan, Asia, Falin Chen [36] investigates and proposes the utilization of the Kuroshio of the North Pacific Ocean current to generate 30GW of clean energy. The flow rate was said to be 1000 times that of the Yangtze River and with an average speed of 1m/s, sustainable power (energy security), reduced Green House Gas emissions and lower energy-purchasing cost can be achieved. The influence of the deflector plate on the performance of modified Savonius vertical axis turbines was investigated in India [24]. Testing eight different positions of the deflector plate, coefficient of power was increased 50% at the optimal position. Various stages of the turbine were also tested.

In the UK,[37] reported about the three bladed 0.8 meter diameter turbine built and tested in a cavitation tunnel and a towing tank at the University of Southampton. The tests which involved power and thrust measurements were able to generate high coefficient of performance (0.46). Investigation and modeling of the hydrokinetic energy resource at the Soderfors channel along the Das River in Norway was also done[38]. Four turbine configurations were studied and it was shown that changes in the power coefficient were prominent only for a vertical shear profile with a strong gradient.

Likewise in Africa, [39] reported that Hydro Alternative Energy Inc. (HAE) has announced its plan to develop a 1MW hydrokinetic project with a South African municipality. The organization plans to install one of its Oceanus tidal power units at a cost of US$20 million. The unit will generate electricity using the Agulhas Current, which flows past the city. The viability of the technology was later investigated and some major challenges facing the development of the technology in the country was raised [40]. Here in Nigeria, West Africa, Hydro Alternative Energy (HAE) has announced joint venture agreement with MRS Holdings Limited to develop hydrokinetic energy projects in the West Africa region and elsewhere. The MOU provides, among other things, for feasibility studies to be undertaken for the development and operation of facilities for the production of tidal electric power, and for the Government of the Republic of Benin and Cameroon to facilitate access to and grant certain exclusivity rights with respect to the project sites that will be selected for the feasibility studies and construction of electricity generation facilities [41].

4. The Nigerian Hydrological Setting

Nigeria is located in the tropical zone of West Africa between latitudes 4°N and 14°N and longitudes 2°2'E and 14°30'E and has a total area of 923,768 km^2. The country is well drained with a close network of rivers and streams. Figure 9 shows some major rivers in Nigeria. There are four principal surface water basins in Nigeria; the Niger River, the Lake Chad, the West Coast (sometimes referred to as the southwestern littoral basins), and the West Central Coast (also known as the southeastern littoral basins) [42].

It can be further subdivided into twelve river basins, i.e. the Benue, Delta and Cross Rivers, the Imo-Anambra, Hadejia-Jama'are, Chad, Sokoto-Rima, Lower-Niger, Upper-Niger, Niger-Delta, Benin-Owena and Ogun-Osun Basins [43], [44]. Figure 10 shows river systems in Nigeria and their organization in River Basins.

About two-thirds of the country lies in the watershed of the Niger River which enters Nigeria towards the Northwestern part of the country and empties itself into the Atlantic Ocean at the Niger Delta [15]. Its major tributaries are the Benue in the Northeast, Kaduna in the Northcentral, Sokoto in the Northwest and Anambra in the Southeast. Several other major rivers in the Southwestern and Southeastern part of the country also empty inside the Atlantic Ocean. River Komadugu Yobe and some other rivers in the Northeastern basin flow into Lake Chad [45]. Other major rivers e.g. Cross, Imo, Ogun, Osun, Benin, Qua Iboe etc. empty directly into the Atlantic Ocean. The majority of small rivers are seasonal [43]. From [43], the drainage systems of these large rivers have typical hydrological patterns which can be grouped into three. The first consists of short, relatively swift rivers which are found mainly in the coastal regions and flow directly into the Atlantic Ocean. The second category are rivers such as the Sokoto-Rima, the Gongola, Kaduna and Hadejia which are rivers mainly of the middle-belt plateau and north which usually have one main peak flood and a flow pattern corresponding to the single maximum rainfall season common in the northern part of the country. The third hydrological pattern is found in the catchments of the Rivers Niger and Benue. These very long rivers, each with several tributaries, have a complex flow pattern. There are usually two floods (the white and black flood) which depend on rainfall outside Nigeria. Figure 11 shows the demarcated hydrological areas of the country together with some major rivers.

5. Potentials of the Hydrokinetic Technology in Nigeria

From [28], the two main characteristics of determining the potential of this marine renewable resource are power density and the size of the recoverable resource. The power density is the extractable power per unit area [46]. This depends on the velocity of flow which is a function of the slope/terrain of the particular portions of the river course– showing that it is site specific. The recoverable resource size provides an understanding of the sustainability of the resource. Nigeria is blessed with a good number of flowing water bodies spanning the length and breadth of the country. With annual rainfall ranging between 1,500 and 4,000 mm in the south (below Latitude 8°N) and between 500 and 1000 mm in the arid northern region, the country experiences flowing rivers and streams for two-thirds of the year [43], [47].

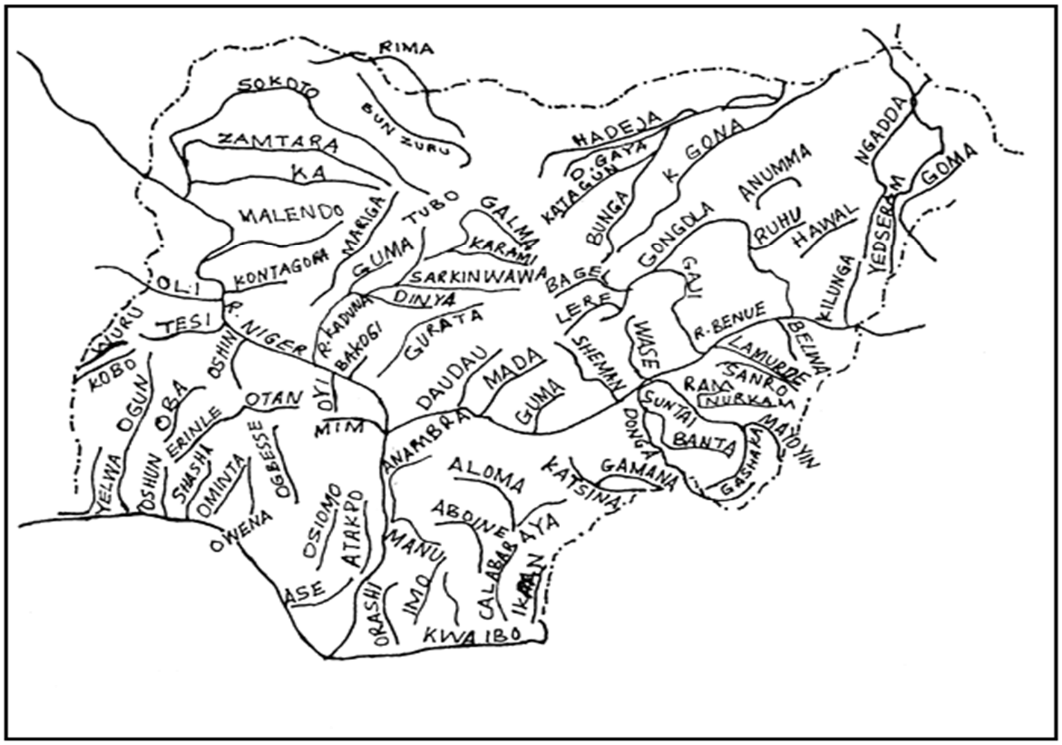


Figure 9: Map of Nigeria showing some Major rivers (Source: [43])

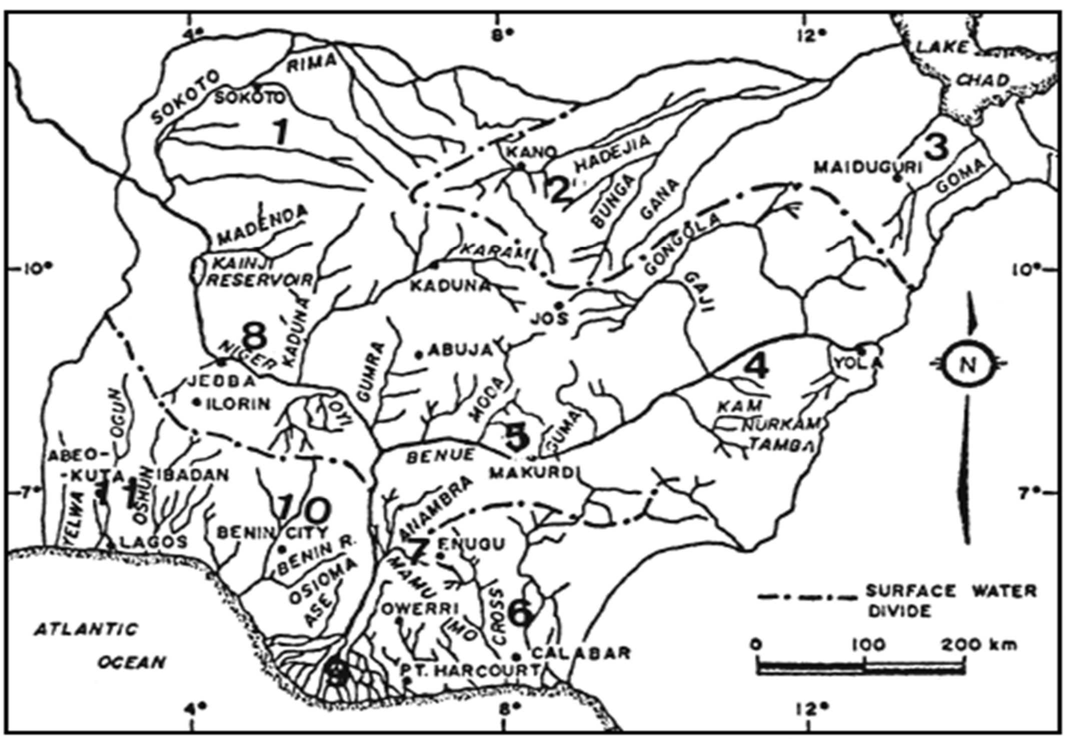


Figure 10: River Systems in Nigeria and their organization into River Basins [43]

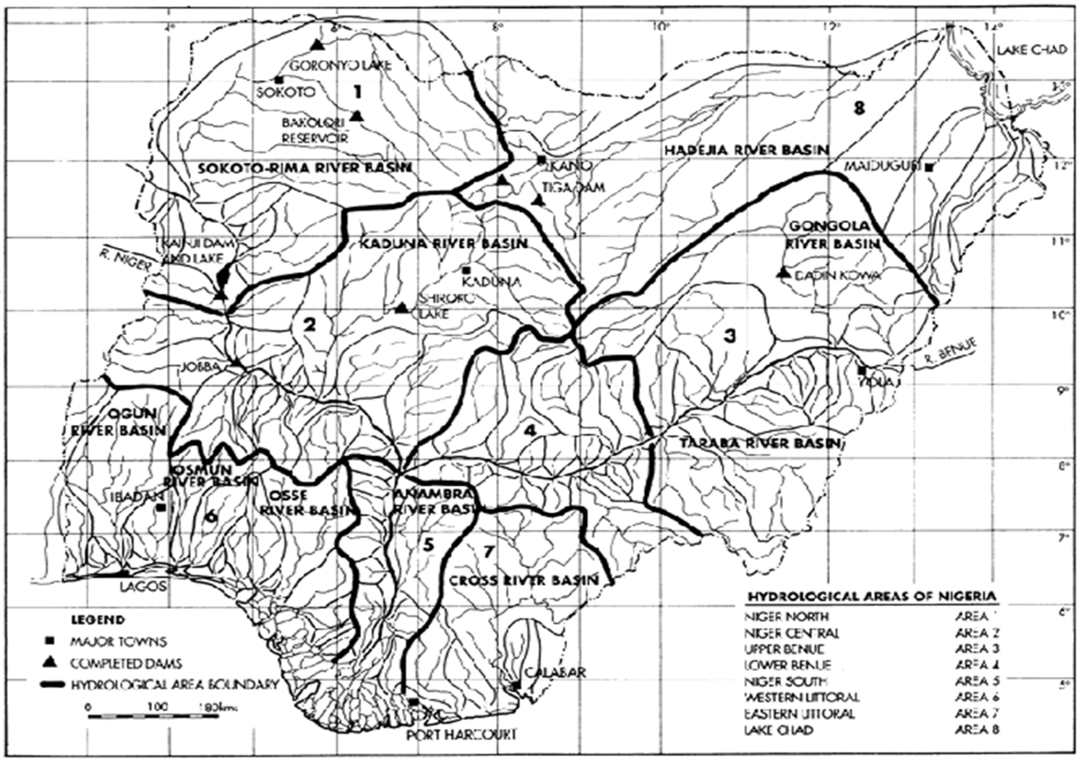


Figure11: The Hydrological Map of Nigeria showing Major Rivers (Source: [43])

The Niger is the major river with Benue as its main tributary. The average discharge for the Niger is 5589m^3/s while that of the Benue is 3400m^3/s although at the point of confluence it exceeds the Niger by volume [48]. However, several other rivers also flow into the Niger along its course and into Lake Chad in the Northeast. The paper [15] lists some of the assessed small hydropower potential of Nigeria and the discharge measurements made at those specific locations. These are presented in Table 1. A multiplication of these discharge values with the measured elevation and constant mass density gives the Segment Specific Theoretical Hydrokinetic Power Resource of the location.

$$P_{th} = \gamma \, Q \, \Delta H \qquad (2)$$

Discharge Q, (m^{3}s^{-1}) and hydraulic head or change in elevation (ΔH, m) over the length of the segment, where γ is the specific weight of water (9800 N m^{-3}). This method was used by the Electric Power Research Institute (EPRI) in determining the theoretical riverine hydrokinetic resource for continental USA [49]. Figures 2, 3 and 4 shows the theoretical estimate of the potential in some Nigerian rivers assuming the slope of the river is 0.3m.

Table 1: Some Rivers in Nigeria and their Average Discharge.

Location	River	Average Discharge (m^3/s)
Donko	Niger	1650
Jebba	Niger	1767
Zungeru II	Kaduna	343
Zungeru I	Kaduna	343
Shiroro	Kaduna	294
Zurubu	Kaduna	55
Gwaram	Jamaare	75
Izom	Gurara	55
Gudi	Mada	41.5
Kafanchan	Kongum	2.2
Kurra II	Sanga	5.5
Richa II	Daffo	4.0
Richa I	Mosari	6.5
Mistakuku	Kurra	2.0
Kombo	Gongola	128
Kiri	Gongola	154
Kramti	Kam	80
Beli	Taraba	266
Garin Dali	Taraba	323
Sarkin	Suntai	20
Danko	Donga	45
Gembu	Katsina Ala	170
Kasimbila	Katsina ala	740
Makurdi	Benue	3185
Lokoja	Niger	6253
Onitsha	Niger	6635
Ifon	Osse	80
Ikom	Cross	759
Afikpo	Cross	1621

Table 2: Some River Locations in Northern Nigeria and their Theoretical Hydrokinetic Potential (assuming a head of 0.3m)

Location	River	Average Discharge (m^3/s)	Theoretical Hydrokinetic Resource
Gwaram, Jigawa	Jamaare	75	0.2205MW
Kafanchan,Kaduna	Kongum	2.2	6.468kW
Kombo, Gombe	Gongola	128	0.3763MW
Kiri, Adamawa	Gongola	154	0.4528MW
Beli, Adamawa	Taraba	266	0.7820MW
Garin Dali, Taraba	Taraba	323	0.9496MW
Sarkin, Taraba	Suntai	20	58.80kW
Danko, Kebbi	Donga	45	0.1323MW
Gembu, Taraba	KatsinaAla	170	0.4998MW
Zurubu , Kaduna	Kaduna	55	0.1617MW

Table 3: Some River Locations in the Central region of Nigeria and their Theoretical Hydrokinetic Potential (assuming a head of 0.3m)

Location	River	Average Discharge (m^3/s)	Theoretical Hydrokinetic Resource
Zungeru,Kaduna	Kaduna	343	1.008MW
Shiroro, Kaduna	Kaduna	294	0.8644MW
Donko	Niger	1650	4.85MW
Jebba	Niger	1767	5.19MW
Kasimbila,Benue	Kat-Ala	740	2.176MW
Makurdi, Benue	Benue	3185	9.4MW
Lokoja, Kogi	Niger	6253	18.4MW

Table 4: Some Rivers Locations in South-western/Eastern part of Nigeria and Theoretical Hydrokinetic Potential (assuming a head of 0.3m)

Location	River	Average Discharge (m^3/s)	Theoretical Hydrokinetic Resource
Onitsha	Niger	6635	19.51MW
Ifon	Osse	80	235kW
Ikom	Cross	759	2.23MW
Afikpo	Cross	1621	4.765MW
Ajura	Ogun	53.36	156.8kW
Apoje	Osun	284.5	836.43kW

6. Adapting the Hydrokinetic Technology in Nigerian Hydrological Setting – The Conditions

Before the technology can be adapted, there are some preliminary investigations that must be made and conditions met. Hydrokinetic energy resource assessment must first be considered. This involves various stages of reconnaissance and prefeasibility studies in order to determine the best location in the course of a river for the deployment of the technology [50]. For optimum power extraction, [51] listed factors to be considered as: velocity of the river, gradient of the river, alignment of the river, width and depth of the river, the contour of the river bottom, depth of the turbine rotor, cross – sectional area of the river channel, discharge volume, roughness of the river bottom, obstacles/floating debris.

It is ideal to pick a section of the river where the velocity of the flow seems to be very high. This could be in places that have a steep gradient with no obstructions and a smooth river bottom and where there is little or no turbulence. The turbine should be installed at a depth that avoids any interference with recreational or navigational uses of water. The turbine mounting structure can be sited in the middle of a straight section of the river closer to the bank, or at a very suitable place in a man – made water channel. It can also be located downstream from an existing hydropower plant where the energy remaining in the water current existing from the turbines in the dams can be reused.

Other important pre – pilot analysis that needs to be done are: fish survival studies, flow studies of particular water body considered, nearness to the power grid, site access, river navigation, state/local permits and Environmental Impact Assessments

7. Research and Development Activities on Hydrokinetic Technology by Some Centres and Institutes in Nigeria

The National Centre for Hydropower Research and Development, a centre under the Energy Commission of Nigeria has been working at developing the technology starting from streams located at the Lower Niger River Basin. Based on records from the Lower Niger River Basin Development Authority (LNRBDA) at Ilorin and careful study of satellite imagery, some rivers flowing from the Southwestern highlands into the Niger were shortlisted and prefeasibility studies were carried out on them at selected locations. River Oshin was studied at Oro in Kwara State, River Ero-Omola is being studied at Ajuba in Kwara State, River Oro was studied at Gubugbu and Lafiagi in Kwara State, River Moshi was studied at Moshi-gada and at Maje village in Kwara State, River Oyi was studied at Ejiba in Kogi State, River Awun was studied at Olooru, Shao and Aderan in Kwara State, River Oshin was studied at Bode Saadu in Kwara State, River at Sabo-n-gada along Bode Saadu-Kaiama road, Kwara state was studied, River Teshi along Oko Olowo-Igbeti road, was observed. Preliminary results obtained thus far indicate the availability of a fair potential of the technology at places like Olooru, Moshi-gada, Lafiagi, Gubugbu, Ejiba and Bode Saadu. Details of the prefeasibility assessment shall be reported in another article. Figures 9 -12 shows gauging activities and prototype developments by some research centres/agencies.

National Agency for Science and Engineering Infrastructure (NASENI) is presently collaborating with the United Nations Industrial Development Organization (UNIDO) on the development of local manufacturing capacity for SHP equipment in the West African sub-region [55][56]. NASENI has completed the design and construction of 10 kilowatts cross-flow turbine for Ketti, SHP plant in Abuja and the design of 2 units of cross flow turbine (2kW + 15kW) proposed for installation at Obasanjo Presidential Library, Abeokuta, Ogun State. These turbine developments were basically for Small Hydropower Projects. The turbine type can also be adapted for Marine Hydrokinetic energy purposes.

8. Challenges of Adapting the Technology in Nigeria

As an emerging technology, the hydrokinetic technology development in Nigeria is also faced with some challenges. These include:

Fig. 12: Ero – Omola river at Ajuba

Fig. 13: Crossflow Turbine developed by NASENI

Fig. 14: Moshi River at Moshigada

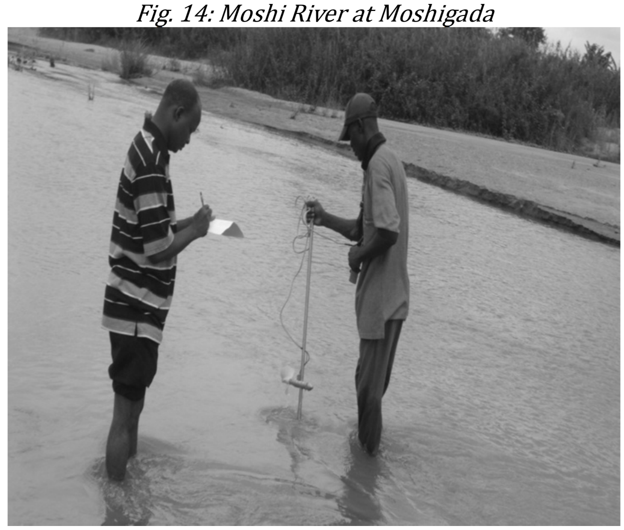


Fig. 15: Oyi river at Ejiba

8.1 Resource assessment

Majority of the assessment done for small hydropower in Nigeria is based on the conventional dam type and not on the velocity, area and discharge of small rivers which are the relevant parameters in hydrokinetics. Even the database for small hydro is not up to date and inadequate [47]. Hence, more hydrokinetic resource assessment efforts need to be made. This necessitates an investigation of macro and micro scale site assessments, determination of annual energy yield and analysis of river characteristics. Development of proper database should also be looked into.

8.2 Awareness creation

Although efforts have been stepped up by the Energy Commission of Nigeria and the United Nations Industrial Development Organisation – International Centre on Small Hydro Power (UNIDO-IC-SHP), through the Renewable Energy Masterplan, on sensitizing the energy stakeholders and national/state/local governments on SHP potentials that abound in the nation [53], [15], more still has to be done, particularly on this new technology as it involves lesser capital investment.

8.3 Inadequate R & D activities

One of the greatest challenges is insufficient knowledge base on the technology [8]. As it may be expected, the technology's capability to supply sustainable power and its overall effectiveness is still being queried. There are little or no research and development efforts, modeling and testing of prototype turbines for the technology. Much multidisciplinary research need to be made to determine the optimum design that would be suitable for Nigerian hydrological settings.

8.4 Environmental Effects

Although the environmental effects of the technology is expected to be minimal, thorough investigations need to be made to ascertain the effects of downstream alterations, aquatic plant and animal life [8]

8.5 Operational Viability

Operational viability is affected by the ability of a given hydrokinetic turbine technology and its support systems to operate in the rivers or streams of interest. For rivers in Nigeria, this means operating in currents and specific discharges that vary seasonally; it also means interaction with sediment, floating and submerged debris and marine populations. Substantial velocity currents, specific power density, and specific discharge are localized in specific river channels. Such channels have riverbeds and banks of sediment, gravel, and cobbles that may migrate, causing the high-specific discharge flow to shift away from an installed turbine.

8.6 Policy/Regulatory Framework

In 2003, the Federal Executive Council (FEC) of Nigeria approved an overall National Energy Policy, which articulates for the use of all viable energy sources for sustainable national development and with the active participation of the private sector in line with government's economic policy [52]. Renewable energy is one of the energy types articulated in the policy. Although the policy stipulates that government shall pay particular attention to development of mini and micro hydropower, not much has been considered in terms of in-stream energy conversion systems. Policy thrusts, frameworks, permits and licenses should be adequately developed for the emerging technology.

9. Way Forward

Comprehensive national resource assessment should be carried out to determine areas where hydrokinetic power can be accessed. Tools (analytical and experimental) are to be developed to identify likely locations and characteristics of potential hydrokinetic resource site locations taking into account available power density, turbulence, river/ocean bed stability and susceptibility to scour or deposition, and community view. Hydrological database should also be created for the velocity/ discharge of rivers and streams. Much R&D activities on the various aspects of the technology should be enhanced; turbine development, mooring, controls, fluid dynamics, system design and performance, environmental impact assessment etc. The government and relevant agencies should popularize energy policy, plans and incentives for investing in hydrokinetic technologies. Continuous capacity building (Human & manufacturing) should also be ensured.

10. Conclusion

In this paper, the hydrokinetic energy conversion technology has been reviewed and its potential and challenges in the Nigerian hydrological set-up considered. Much effort has been concentrated on dams for hydropower over the years and much resource assessment and site developments have been undertaken. Research thrusts should now shift towards this hydrokinetic technology as it holds vital advantage in its ability to be deployed in off – grid locations at low investment cost. The hydrokinetic industry in Nigeria is at the infancy (proof of concept) stage and needs to grow. With rivers flowing for the major part of the year, the technology will be useful in ameliorating the energy crises in the nation.

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