TOWARDS INTRODUCING PUMP STORAGE HYDRO FOR SUSTAINABLE RURAL ELECTRIFICATION AND ENERGY POVERTY REDUCTION

MBAMALUIKEM, P. O. & AIYELABOWO, O. P.

Electrical / Electronic Engineering Department,
The Federal Polytechnic Ilaro, Ogun State, Nigeria

E-mail: mbamaluikem@gmail.com

A PAPER PRESENTED AT THE

ACADEMIC STAFF UNION OF POLYTECHNICS (ASUP)

13TH NATIONAL CONFERENCE HELD AT KANO STATE POLYTECHNIC, KANO

7th – 10th NOVEMBER, 2016

ABSTRACT

There is massive deployable hydro power potential in Nigeria but less than 7 % of the available hydro potentials have been harnessed. This paper evaluates the current status of Pumped Storage Hydro (PSH) resources in Nigeria, its deployment, challenges for exploiting it for rural electrification and how it fits in as a recipe for reducing the energy poverty of rural dwellers and Nigeria as a whole. PSH is a very appropriate source of electricity for rural electrification in Nigeria since the potential for small hydro is usually found within the suburbs of the urban areas. In this study, the deployment of pumped storage hydro was discussed from the view point of providing reliable electricity to thousands of people living in the rural areas. Secondary source of information gathering was used in this study. Expert's knowledge from journals, conference papers, reports, and other documents was leveraged on the subject. The analysis in this work was done using a textual method. Based on the analysis, Nigeria has over 278 unexploited small hydro sites with an estimated capacity of 3.5 GW. It was observed that PSH can effectively contribute to sustainable rural electrification in Nigeria, hence, improving the economic growth among the rural dwellers and reducing the energy poverty of Nigeria globally. Furthermore, employing pumped storage hydro will have significant impact in meeting up 70% to 80% electrification of rural areas by 2030.

Keywords: Pumped storage hydro, rural electrification, energy poverty, Small hydro, reliable electricity

1.0 INTRODUCTION

Nigeria's energy supply is heavily dependent on fossil fuel and this sector for about two decades or more has experienced weighty bombardments and these have led to frequent or total shut-down of service providers whose operations depend on the energy supplied from this sector (Julia et al, 2008; Ubani et al, 2013). Sequel to this, communities that would have been connected to the power grid are left unconnected due to inadequate power generated; hence increasing the country's energy poverty profile. Energy consumption per capita is one of the indicators of a country's level of development and for Nigeria to meet the world standard of at least 1

KWh/year of energy per person among the rural dwellers, steady energy supply becomes a vital necessity. Hence, there is a renewed interest on how to develop and expand the capacity of electrical energy generation, transmission and distribution in the country more especially for the rural dwellers. This interest can best be contented using hydro energy potentials. Therefore, the enough hydro potential energy resources in our country can be employed to close this gap (Roseline et al, 2012). Furthermore, less than 4,000 MW of electricity are being generated from the available sources for about 182 million people. This of course, has weakened the zeal to achieve industrialization and consequently economic growth as outlined in vision 2020 (Akin, 2008). Nevertheless, deployment of available hydro energy potentials will facilitate the electrification, improve the general wellbeing of people and reduce energy poverty among the rural areas.

Energy poverty is the shortage of adequate modern energy for the basic essential energy services which includes but not limited to basic needs of cooking (using clean cooking facilities that do not cause air pollution), heating, manufacturing, warming, cooling and lighting of schools, small scale businesses, health centers, offices and homes (Agba, 2011). Growing global oil prices, energy security and the need to tackle climate change are putting energy at the centre of public policy especially in the developed countries. But currently Nigeria is not much concerned with these crises because she is heavily being affected by energy poverty which condemns millions of people to live in total poverty. (IEA, 2002) argues that only about 15% of the population in Africa has electricity and the remaining 85% which amounts to over 1.6 billion people have no electricity, the majority of which are in Nigeria. More so, greater percentage of over 2.5 billion people cooking with biomass in the world, live in Nigeria. This means that this population have no or limited access to electricity from morning to morning for their businesses, radio, modern communication gadgets, education and health facilities, lighting, cooling and water supply (Omojolaibi, 2014). This paper therefore, evaluates the current status of Pumped

Storage Hydro (PSH) resources in Nigeria, its deployment, challenges for exploiting it for rural electrification and how it fits in as a recipe for reducing the energy poverty of rural dwellers and Nigeria as a whole.

2.0 NIGERIA RURAL ELECTRIFICATION STATUS

The Rural Electrification Agency (REA) in Nigeria was established by section 88(1) of the Electric Power Sector Reform Act (EPSRA) 2005 in 1981. According to (REA, 2014), they body is to:

- Promote Rural Electrification in Nigeria
- Co-ordinate Rural Electrification Programmers in Nigeria
- Administer the Rural Electrification Fund (REF) to promote and support through public and private sector participation

This body began fulfilling their primary responsibility of electrifying the rural areas of the 36 state in Nigeria by extending the Nigeria National Grid System to provide electricity to Local Government Headquarters. For the meantime, this resulted in greater access to electricity by Local Governments and some consumers within the immediate environ (Anumaka, 2012). However, the agency was closed down in September 2009 by the Federal Government without achieving its set goals. In late 2011, this agency was reopened. Meanwhile, no budgetary provision was made for the body in the 2012 budget. But in 2013 budget, a sum of N6, 456, 217, 274 (FRN Budget, 2013) was voted for the body out of the N 74, 262, 379, 894 budgeted for the power ministry representing 8.69% of the total power budget (Elusakin et al, 2014). Notwithstanding, the target groups are yet to see electricity. In 2010, out of an African total population of about 590 million people without electricity, 585 million of them are found in Sub-Saharan Africa (see Figure 2). The average rural electricity access level in SSA region is 14% as compared to 98.4% in North Africa, 60% in South Asia, 74% in Latin America, and 72% in Middle East (IEA, 2012). (Rosnes & Vennemo, 2008), argues that levels of rural electrification vary from country to country even within a region. Figure 2 reveals that all West African countries have a wide difference in urban and rural electrification access level. Currently, it is estimated that only about 20% of rural households have access to electricity and the rest rely heavily on fuel-wood, candle, kerosene lamps and other unhealthy sources of energy to light - up their environments (Akpojedje et al, 2016; REA, 2014).

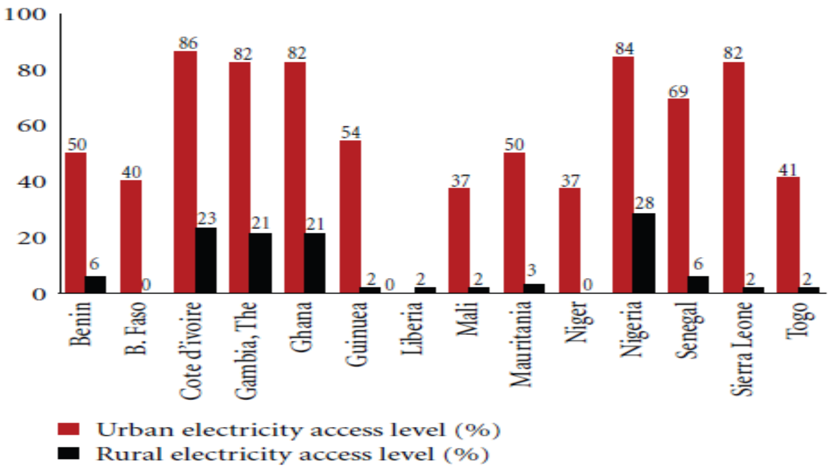

Figure 2: Electricity access levels in West Africa (2005)

Source: (Chiyembekezo et al, 2012)

3.0 SMALL HYDRO POWER POTENTIALS IN NIGERIA

Hydro electricity is the electricity generated from utilizing the potential energy of water at a high head. It is the most widely used form of renewable energy globally, accounting for about 16 percent of global electricity generation (Olayinka, 2010). It is produced in 150 countries, with the Asia-Pacific region generating 32 percent of global hydropower in 2010. Table 1 shows the ten (10) largest counties that produce hydroelectric power. To be sure, in 2010, electricity generation using hydro power plants stood at about 3,427 terawatt-hours of electricity and was expected yearly to have about 3.1% increase for the next 25 years (Martin–Amouroux, 2003; Jayesh et al, 2013). In Nigeria, hydro power has the biggest potential sources of electricity in our country but these potentials remain largely underutilized because of the country's preference for large dams. This prevents the adoption of a new approach to hydroelectricity generation that involves the use of cost effective, easy to erect and ecological friendly mini, micro and Pico hydro power plants. Table 2, 3 & 4 depict some of the water courses in Nigeria. Therefore, it is obvious that several decentralized mini, micro and Pico hydro power plants can generate enough electricity to meet the country's energy rural electrification needs. (Abubakar, 2009) agrees that according to the water flow and capacities that can be generated in Nigeria, small hydro power can be categorized into:

- Small hydro – > 2 MW ≤ 10 MW
- Mini hydro – ≥ 100 KW ≤ 2 MW
- micro hydro – ≥ 5 KW ≤ 100 KW
- Pico hydro – < 5 KW

Table 1: Ten Top Largest Hydro Power Producer Country

S/N	Country	Annual Hydroelectric production (TWh)	Installed capacity (GW)	Capacity factor	% of total Capacity
1	Brazil	363.8	69.08	0.56	85.56
2	Canada	369.5	88.974	0.59	61.12
3	China	652.05	196.79	0.37	22.25
4	India	115.6	33.6	0.43	15.8
5	Japan	69.2	27.229	0.37	7.21
6	Norway	140.5	27.528	0.49	98.25
7	Russia	167	45	0.42	17.64
8	Sweden	65.5	16.209	0.46	44.34
9	United States	250.6	79.511	0.42	5.74
10	Venezuela	85.96	14.622	0.67	69.2

Source: (EA.NRW., 2014)

Table 2: Small Hydro Potentials in Surveyed States in Nigeria

S/N	State (Pre 1980)	River Basin	Sites	Total MW
1	Sokoto	Sokoto-Rima	22	30.6
2	Katsina	Sokoto-Rima	11	8
3	Niger	Niger	30	117.6
4	Kaduna	Niger	19	59.2

5	Kwara	Niger	12	38.8
6	Kano	Hadejia-Jamaare	28	46.2
7	Borno	Chad	28	20.8
8	Bauchi	Upper Benue	20	42.6
9	Gongola	Upper Benue	38	162.7
10	Plateau	Lower Benue	32	110.4
11	Benue	Lower Benue	19	69.2
12	Rivers	Cross River	18	258.1
Total			277	734.2

Source: (Manohar & Adeyanju, 2009)

Table 3: NEPA estimate of current exploitable hydro power sites in Nigeria

S/N	Location	River	Potential Capacity (MW)	S/N	Location	River	Potential Capacity (MW)
1	Zungeru II	Kaduna	225	**17**	Beli	Taraba	240
2	Zungeru I	Kaduna	450	**18**	Garin Dali	Taraba	135
3	Zurubu	Kaduna	500	**19**	Sarkin Danko	Suntai	45
4	Gwaram	Jamaare	20	**20**	Gembu	Dongu	130
5	Izom	Gurara	10	**21**	Kasimbila	Katsina Ala	30
6	Gudi	Mada	40	**22**	Katsina Ala	Katsina Ala	260
7	Kafanchan	Kongum	5	**23**	Makurdi	Benue	1, 060
8	Kurra II	Sanga	25	**24**	Lokoja	Niger	1, 950
9	Kurra I	Sanga	15	**25**	Onisha	Niger	1, 050
10	Richa II	Daffo	25	**26**	Ifon	Osse	30

11	Richa	Mosari	35	**27**	Ikom	Cross	730
12	Mistakuku	Kurra	20	**28**	Afokpo	Cross	180
13	Korubo	Gongola	35	**29**	Atan	Cross	180
14	Kiri	Gongola	40	**30**	Gurara	Gurara	300
15	Yola	Benue	360	**31**	Mambilla	Danga	3, 960
16	Karamti	Kam	115				
Total							**12, 220**

Source: (Olayinka, 2010)

Table 4: Summary of Small Hydro Potential Sites in Nigeria

S/N	State	Potential Sites	Cumulative Power Estimate (MW)	S/N	State	Potential Sites	Cumulative Power Estimate (MW)
1	Adamawa	3	28.600	**16**	Katsina	11	234.34
2	Akwa Ibom	13		**17**	Kebbi	1	
3	Bauchi	1	0.150	**18**	Kogi	2	1.050
4	Benue	10	1.306 (1 Site)	**19**	kwara	4	5.200
5	Cross River	5	3.000	**20**	Nassarawa	3	0.454
6	Delta	1	1.000	**21**	Niger	11	110.580
7	Ebonyi	5	1.399	**22**	Ogun	13	15.610
8	Edo	5	3.828	**23**	Ondo	1	1.300

9	Ekiti	6	1.2472	**24**	Osun	8	2.622
10	Enugu	1		**25**	Oyo	3	1.062
11	FCT	6		**26**	Plateau	14	89.100
12	Gombe	2	35.099	**27**	Sokoto	1	
13	Imo	71		**28**	Taraba	9	134.720
14	Kaduna	15	25.000	**29**	Yobe	5	
15	Kano	6	30.000	**30**	Zamfara	16	

Source: (Kela et al, 2012)

4.0 PUMPED STORAGE HYDRO

Pumped storage hydro (PSH) plant is established machinery for energy storage. It stores potential energy from water that is raised against gravity. The first of its kind was constructed in the early 20th century in Schaffhausen, Switzerland. This system was started in 1909 and is still working up till now. As years go by, pumped storage hydro system becomes more attractive and recently it was heavily employed for supplying peak energy (Torres, 2011). It is the most widely used method of mini hydro-electric power systems and is becoming domineering because of its cost effectiveness. It does not require building a base load plant to cushion the effect of peak demand; instead the peak load demand is taking care of by increasing the peak hydro power production via pumping the already used water from the underground reservoir into the overhead reservoir. This can be achieved by swiftly configuring the generator to work as a motor for pumping up water during the trough periods (Jayesh et al, 2013). It stores energy in the form of water in an upper reservoir during low electricity demand and during the high electricity demand; the stored water is released through the penstock to the power house via the turbine where electrical power is generated in the same way as conventional hydro power plants (ESA, 2016; Kela et al, 2012).

Pumped storage hydroelectric projects have been providing energy storage capacity in the United States (U.S.) and Europe since 1920s. Nowadays, U.S. has about 40 pumped storage hydro projects in operation which provides over 20, 000 MW (ESA, 2016). Other countries in the world that have deployed PSH and their capacities are shown in Table 5. Furthermore, PSH is a good prospect for a better electricity future to rural communities across Nigeria and for replacing every other unhealthy means of energy generation for the purpose of lighting, warming, cooling, powering radios, TVs and machinery, and providing other livelihood opportunities. Deploying PSH will go a long way in providing reliable electricity to thousands of people living in the rural areas. Moreover, the water for electricity generation can be sidetracked from a river via a barrier. The run-of-river type of electricity generation is more profitable for a Pico hydro power generation because it reduces the investment cost per KW of electricity (Chiyembekezo et al, 2012). The heart of a PSH is the turbine, which drives an alternator for electricity generation. There are different types of turbine and its choice of use is largely dependent on the head of water and flow rate. Table 6 shows the types of turbine and nature.

Table 5: PSH capacity in some countries in the world

S/N	Country				Generation capacity (GW)
1	**North America**				**22. 2**
	Canada	0.2			
	United States	22			
2	**Central & south America**				**1**
	Argentina	1			
3	**Europe**				**44**
	Austria	4.4	Luxembourg	1.1	
	Belgium	1.3	Norway	1.4	
	Bulgaria	0.9	Poland	1.4	
	Croatia	0.3	Portugal	1.0	
	Czech Republic	1.1	Serbia	0.6	
	France	4.3	Slovakia	0.9	
	Germany	6.7	Spain	5.3	
	Greece	0.6	Sweden	0.1	
	Ireland	0.3	Switzerland	1.8	
	Italy	7.5	United Kingdom	2.7	
4	**Eurasia**				**2**
	Lithuania	0.8	Russia	1.2	

5		**Africa**			**2**
	Morocco	0.5	South Africa	1	
	Cameroon	0.5			
6		**Asia & Oceania**			**33**
	Australia	1	South Korea	4	
	Japan	25	Taiwan	3	
		World			**105**

Table 6: Types of Turbine and their Nature

S/N	Name	Type of Head	Description
1	**Pelton** turbine	for high head, low flow	Consists of a set of small buckets arranged around a wheel onto which one or more jets of water are arranged to impact.
2	**Francis** turbine	lower head and higher flow	It has a spiral casing that directs the water flow through vanes on a rotor.
3	**Cross-flow** or **Banki** turbines	lower head and higher flow	They made as a series of curved blades fixed between the perimeters of two disks to make a cylinder. The water flows in at one side of the cylinder and out of the other, driving the blades around. They are much easier to make than most other designs.
4	**Propeller**	very low head and	It has fixed blades, like a boat propeller. A more

	turbine	large flow	complex version, the Kaplan turbine, has blades that can be adjusted in pitch relative to the flow.
5	**River current turbine**	virtually no head	It is like a wind-turbine immersed in water, it can be used to extract power from a large flow in a river, where there is virtually no head.

5.0 CHALLENGES

In the face of all the potentials in the PSH in all the rural areas in Nigeria, rural electrification is still faced with acute challenges (Wim, 2007) which are severe impediments to achieving at least the world's 1 KWh/year per person before 2030. Some of the challenges are:

- Government interest on large scale hydro power
- Lack of enlightenment campaigns about the advantages of PSH
- Lack of programmes for capacity building and training on PSH to uphold and accelerate sustainable development in this area.
- Government policy on electricity generation and distribution
- Financial barriers in funding the PSH projects. Government should support any investor coming to invest in this area with grants. Also, there should be incentives and subsidies or even loans with a smaller amount of interest and flexible settlement plans so as to overcome the impediment.
- Lack of manufacturing plant for components of PSH turbines and other components.
- Lack of access to appropriate technologies in the mini, micro and Pico hydro

- Lack of infrastructure for manufacturing, installation and operation: Nigeria does not have any facility to manufacture even the most rudimentary turbines or parts that might be critical in maintenance of PSH schemes.
- Lack of local capacity to design and develop small hydropower schemes for areas sometimes considered too remote: Nigeria has no specialization to undertake feasibility studies that would include detailed design and costing of the schemes to make a meaningful impact on utilization of small hydro sites.

6.0 CONCLUSION

Nigeria has PSH potential capacity to generate over 3.5 GW of electricity in all the communities in the local government areas of the 36 states across the six geopolitical zones of the country which is more than enough to cater for its rural electrification needs. The overwhelming demand for energy by all and sundry in the nation makes it possible to earn very high returns on investment and hence, the investment opportunities in this area are highly attractive for any investor.

Moreover, PSH is a fast means of providing electricity to rural communities and it will be a very good outstanding source regarding steady electricity supply and generation cost over a long period of time. This will offer 24 hours electricity for lighting, TV, running machinery, refrigerators, supporting small businesses and communications for homes, schools, clinics and community buildings. When this is done, it is more likely that people will stay in the villages and do their business. Hence, rural urban migration will be significantly reduced. PSH is environmental friendly unlike the large-scale hydro that requires considerable areas of land to be flooded to provide reservoirs and imposes serious challenge on water management agencies. PSH takes only a small amount of water and have small reservoir. Therefore, it imposes a very little water management problem and it reduces greenhouse gas emissions and local pollution from fossil fuels. Finally, exploring PSH will reduce energy poverty of the country thereby making adequate modern energy for the basic essential energy services which includes but not limited to basic needs of cooking (using clean cooking facilities that do not cause air pollution), heating, manufacturing, warming, cooling and lighting of schools, small scale businesses, health centers, offices and homes.

REFERENCES

Abubakar, S. S. (2009). Strategic Developments In Renewable Energy In Nigeria. *International Association for Energy Economics* .

Agba, M. S. (2011). Energy poverty and the leadership question in Nigeria: An overview and implication for the future. *Journal of Public Administration and Policy Research, 3*(2), 48 - 51. Retrieved December 3, 2015, from Retrieved from http://www.academicjournals.org/jpapr on 03/12/2015

Akin, I. (2008). Nigeria's Dual Energy Problems: Policy Issues and Challenges.

Akpojedje, F. O., Onogbotsere, M. E., Mormah, E. C., & Onogbostere, P. E. (2016). A Comprehensive Review of Nigeria Electric Power Transmission Issues and Rural Electrification Challenges. *International Journal of Engineering Trends and Technology (IJETT), 31*(1). Retrieved from http://www.ijettjournal.org

Anumaka, M. C. (2012). Analysis of Technical losses in Electrical Power System (Nigerian 330KV Network as a case study). *International Journal of Research and Review in applied Science, 12*(2), 320.

Chiyembekezo, S. K., Cuthbert, Z. K., & Torbjorn, K. N. (2012). Potential of Small-Scale Hydropower for Electricity Generation in Sub-Saharan Africa . *International Scholarly Research Network, ISRN Renewable Energy, 2012*.

Chiyembekezo, S. K., Cuthbert, Z. K., & Torbjorn, K. N. (2012). Energy Potential of Small-Scale Hydropower for Electricity Generation in Sub-Saharan Africa. *International Scholarly Research Network.*

Elusakin, J. E., Ajide, O. O., & Diji, J. C. (2014). Challenges of sustaining off-grid power generation in Nigeria rural communities. *African Journal of Engineering Research*, *2*(2), 51 - 57.

Energy Agency.NRW. (2014). *what is pumped storage plant?* Retrieved September 6, 2016, from http://www.energieagentur.nrw.de

Energy Storage Association. (2016). *Pumped Hydroelectric Storage.* Retrieved September 6, 2016, from http://energystorage.org/energy-storage/technologies/pumped-hydroelectric-storage

Energy Storage Association. (2016). *pumped Storage Hydro*. Retrieved September 16, 2016, from http://energystorage.org/energy-storage/technologies/pumped-hydroelectric-storage

International Energy Agency. (2012). *Access to electricity.* Paris: Report, Published by the International Energy Agency,. Retrieved from http://www.iea.org/weo/electricity.asp.

International Energy Agency. (2002). *Energy and poverty: IAEA Bulletin.* Paris: International Energy and Democratic.

Jayesh, D. S., Arun, K. D., Patil, P. N., & Shailendra, K. D. (2013). Small Pumped Storage Hydro Power Plant – A Feasibility Study for MIDC Dhule, Maharashtra. *Global Journal of Researches in Engineering Electrical and Electronics Engineering*, *13*(12).

Julia, K. D., Nick, H., Kyle, M., & Allison, R. (2008). *The Energy Crisis of Nigeria: An Overview and Implications for the Future* . U.S.A.: The University of Chicago.

Kela, R., Kaisan, M. U., & Ahmad, T. (2012). Potentials of Small Hydro Power in Nigeria: The Current Status and Investment Opportunities. *International Journal of Scientific & Engineering Research, 3*(5).

Manohar, K., & Adeyanju, A. A. (2009). Hydro Power Energy Resources in Nigeria. *Journal of Engineering and Applied Sciences, 4*(1), 68 - 73.

Martin–Amouroux, J. M. (2003). Small Hydro in the World Electricity Supply:. *Contrasted Incentives to Growth*(2).

Murphy, T. (2011). *Do the Math: Using physics and estimation to assess energy growth options.* Retrieved August 14, 2016, from : http://physics.ucsd.edu/do-the-math/2011/11/pump-up-the-storage/

Olayinka, S. O. (2010). Energy Utilization and Renewable Energy Sources in Nigeria. *Journal of Engineering and Applied Sciences, 5*(2), 171 - 177.

Omojolaibi, J. A. (2014). Reducing Energy Poverty in Africa: Barriers and the Way Forward. *International Association for Energy Economics*.

Roseline, K., Kaisan, M. U., & Ahmad, T. (2012). Potentials of Small Hydro Power in Nigeria: The Current Status and Investment Opportunities. *International Journal of Scientific & Engineering Research, 3*(5).

Rosnes, O., & Vennemo, H. (2008). Powering up: costing power infrastructure spending needs in Sub-Saharan Africa. *Africa Infrastructure Country Diagnostic (AICD), 5*.

Rural Electrification Agency. (2014). *'New National Rural Electrification Implementation Strategy and Plan*.

Torres, O. (2011). *Life Cycle Assessment of a Pumped Storage Power Plant.* University of Science and Technology, Department of Energy and Process Engineering, Norwegian.

Ubani, O. J., Umeh, L., & Ugwu, L. N. (2013). Analysis of the Electricity Consumption in the South – East Geopolitical Region of Nigeria. *Journal of Energy Technologies and Policy*, *3*(1).

Wim, J. K. (2007). *Small Hydropower Development In Africa*. ESI Africa Issues 2.