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Off-Grid Small Hydropower for Rural Development in Nigeria

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Abstract:

A comprehensive review of small hydropower development in rural areas of Nigeria and off-grid systems was carried out. Major researches conducted at potential sites for small hydropower development and current trends as well as the role of off-grid networks were reported. All the six geo-political regions in Nigeria can possibly be taken care by the works under review. Small hydropower potential showed that 5.13-5000 kW is enough to cater for an average rural community in Nigeria and this is achievable in many identified SHP sites. The creation of decentralized off-grid networks at potential sites would significantly increase electricity accessibility. Very small percentage of identified SHP potential is so far harnessed. Works are still on-going and huge opportunities for investment and electricity generation exist in small hydropower systems regarding rural electrification in Nigeria.

Keywords **— small, hydropower, rural, Nigeria, off-grid**

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I. INTRODUCTION

Energy has proven to be a powerful engine for social and economic enhancement. Provision of minimum access to energy services for the larger proportion of a population has become mandatory for countries to develop beyond a subsistence economy. Access to modern energy services is a direct measure of economic growth and poverty alleviation. This argument is supported by many studies that indicate strong correlation between economic growth and energy consumption per capita [1]. Exponential rise in population and developmental growth continue to increase the demands for sustainable energy in most developing nations as is the case with Nigeria. This situation is made worst by lack of infrastructures for providing and extending sufficient energy especially to rural areas. Renewable energy is the solution to energy poverty. Its systems have transformed the ability to deliver secure and affordable electricity to rural communities all over the world. Renewable energy systems surely play a vital role in breaking a cycle of energy poverty that has held back socio-economic progress for hundreds of millions of people [2, 3].

Fagbohun [4] reported that electricity has become a necessary tool for sustainable development of countries around the globe. Substantial number of rural populace in Nigeria (up to 65%) do not have access to electricity and the remaining few ones only witness an epileptic supply. These only constitute a barrier for development in the rural areas. Fagbohun [4] and Zarma [5] agreed that small hydropower (SHP) is a potential renewable energy technology that is very suitable for rural electrification in Nigeria. This finds support in the availability of rivers, streams and run-off waters that have the capacities to generate hydroelectric energy in the majority parts of rural areas. Off-grid SHP systems will mitigate energy deficiency in most parts of rural Nigeria.

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Reference [4] attested that many results from analyses showed that theoretical electrical power ranging from 5.13 kW to 5,000 kW that is enough to cater for an average rural community loads is realizable in Nigeria if the identified small hydropower sites are developed. The aim of this study is to make an extensive review of off-grid SHP systems in rural areas of Nigeria with the principal objective of spreading the awareness for the dare need of such systems for a diversified and reliable energy-mix option.

II. Small Hydropower Systems

Hydropower plants are generally classified on the basis of their power output. Small hydropower plants have generating capacity of up to 10 MW and the scheme can serve small towns or big enterprises. This type of hydropower has low environmental impact when compared to large hydropower. A small hydropower plant may be connected to conventional electrical distribution networks as a source of low-cost renewable energy. The system could also be built in isolated areas that are not favourable to be served from a network or unconnected to the grid. SHP can be further divided into mini hydropower (less than 1000 kW), micro hydropower (less than 100 kW) and pico hydropower that has a capacity of less than 5 kW. Small hydropower is best suited for smaller communities, single families or small enterprise [6, 7].

The hydropower sector in Nigeria witnessed about 360% growth between 1971 and 2005 but yet only about 5% of the vast small hydropower (SHP) potential is tapped by the few plants built between 1923 and 1964 as reported by Ohunakin et al. [1]. The study evaluated small hydropower development and examined the situation in Nigeria with respect to the established policies and Energy Power Sector Reform (EPSR) Act 2005. It was established that operating and maintenance costs are very favourable to the development of SHP in the country. The work further reported that the Nigerian Government took steps to diversify energy sources to encourage private investments in the energy sector through reforms and promote renewable energy development. However, that might not be adequate as there still remained some barriers against SHP development in the nation. The study concluded that for Nigeria to promote renewable energy and attract both indigenous and foreign investments for quick adoption and rapid expansion of SHP technologies the government must incorporate subsidies, feed-in-tariffs, and framework for Price Purchase Agreements (PPA) into its policies.

III. Small Hydropower Potential in Nigeria

Nigeria is blessed with substantial amount of small hydropower potential. Within its rural areas and spread throughout all parts of the country, it is estimated that over 278 small rivers with a total capacity of 734MW are identified as SHP potential sites for micro, mini and Pico hydropower systems [6, 8, 9]. Shobayo et al. [10] demonstrated that off -grid small hydropower generation from Opeki River, a tributary of Ogun River, in the South-West region of Nigeria would improve electricity supply to its nearby rural communities. In the work, mean daily flow records for seven years were used to establish a flow duration curve (FDC) for the river and a medium range of heads were evaluated. Annual optimal operation period (To) and rated output (Pk) were determined and power duration curve (PDC) for a proposed plant at the site of interest derived. Annual energy production (Ek) and capacity factor (C) for the plant were projected from the PDC. The study confirmed the possibility of exploiting SHP as analysis from a single Kaplan turbine at a net head of 46.5 m, yielded values of Pk, To, Ek and C as 8.8 MW, 148 days, 50,018 MWh, and 65.1% respectively at site. Otun et al. [3] indicated that a SHP on the axis of Kangimi Reservoir Dam can sufficiently meet an estimated 872.566 kW total energy need of the communities surrounding an area of the Kangimi River in Kaduna State, North-West region of Nigeria. The study established that the Kangimi Reservoir can potentially generate 1.109MW and 0.692 MW if its axis is placed at 612m and 604m above sea level respectively. Measures were taken such that the upper and lower limits of heads chosen at the proposed hydropower site sufficiently meet the

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demands for power generation and irrigation purposes. Other factors like: possible environmental impacts, implications and requirements for developing the proposed Kangimi small hydropower plant were assessed. The study affirmed that the scheme if actualized will improve the socio-economic development of the neighbouring communities around Kangimi River area. Otuagoma [11] in another study reported the small hydropower potential of River Iyi-Ukwu in Oshimili North Local Government Area of Delta State, Southt-South region of Nigeria to be 1.83 MW.

From the same perspective Fagbohun [4] studied and reported the potentials of small hydropower generation from Itapaji dam in Ekiti State, South-Western region of Nigeria. The study established an estimated hydropower potential of the dam at about 1.30MW with an average annual mean discharge of $8.33m^3/s$ and a reservoir capacity balance of 1.922x109 m^3/year. Other evaluated parameters were; the maximum annual discharge of the dam, average nominal flow discharge and average minimal flow each at 23.24, 8.33 and 1.78 m^3/s respectively. The environmental assessment for overall viability and required components for small hydropower scheme at the site were also investigated. The study proposed that generated electricity from the scheme can easily be extended to surrounding communities along the grid-line without major challenges to mitigate the problem of poor electricity supply in the rural area. Fagbohun and Omotoso in [7] also investigated the viability of Elemi River in Ado-Ekiti, Soth-West region of Nigeria for off-grid SHP application as a possible source of electricity to solve incessant power failures in three surrounding higher institutions of learning. FDC was determined by analysis of 11 years (2005-2015) hydrological data for the study area. The mean average velocity of the stream was calculated as 1.21m/s. Both average annual flow discharge and average minimal flow were evaluated to be 45.9 and 9.1 m^3/s respectively. The study estimated hydropower potential of 2.21MW for the river. However, the work reported that the yield capacity of Elemi River for power generation with a diversion scheme could not provide the power requirement for any of the 3 higher institutions within its course. This, the study attributed to the relatively flat terrain of the river with a maximum derivable head of 8 m. The work recommended that a dam be constructed for an impounded scheme with a minimum gross head of 20 m in order to adequately serve the needs of at least one of the surrounding institutions.

Table 1: Small Hydro Potential in Surveyed States of Nigeria (A dopted from REMP [12])

State (Pre 1980)	River Basin	Total Sites	Total Capacity (MW)
Sokoto	Sokoto-Rima	22	30.6
Katsina	Sokoto-Rima	11	8.0
Niger	Niger	30	117.6
Kaduna	Niger	19	59.2
Kwara	Niger	12	38.8
Kano	Hadejia-	28	46.2
Borno	Jamaare	28	20.8
Bauchi	Chad	20	42.6
Gongola	Upper Benue	38	162.7
Plateau	Upper Benue	32	110.4
Benue	Lower Benue	19	69.2
Rivers	Lower Benue	18	258.1
	Cross River	277	964.2
	TOTAL		

This potential if harnessed will significantly ease rural electrification and improve the standard of living in most rural parts of Nigeria. Adejumobi et al. [13] reported a surveyed and analyzed potential hydropower sites for rural electrification scheme in Nigeria where available hydrological data was used. In the study the average energy consumption patterns for rural communities in some selected sites were investigated and identified. The results from analysis in the work showed that theoretical electrical power range (5.13-5000 kW) is enough to cater for an average rural community in Nigeria and this is achievable in many locations if identified SHP sites are developed. With regards to investment and employment opportunities Kela et al. [14] indicated that there are investment opportunities in the small hydropower potential of Nigeria. The study observed that Nigeria has the potentials of over 277 dispersed small hydropower sites that can cumulatively generate about 734.2MW. By the year 2005 only 30MW has been harnessed out of the potential. The work claimed

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that as of 2012 the SHP potential had reached 3500MW and that presents huge investment opportunities in provision of electricity to the rural areas of Nigeria.

IV. Existing SHP Sites and Off-Grid Systems in Rural Areas of Nigeria

A private company, Nigerian Electricity Supply Company (NESCO) started the development of small hydropower in 1929 with an initial installation of 1000 kVA (800 kW) hydroelectric power plant in Kurra falls, Jos, North-Cenral region of Nigeria. The installed capacity later reached about 30 MW [15]. References [5, 16] reported about existing small hydro schemes in Nigeria. This was also indicated by Federal Ministry of Power and Steel [17] through the Renewable Electricity Action Program (REAP).

Table 2: Small Hydro Schemes in Existence in Nigeria
(Adopted from [5, 12, 17)

River	State	Installed Capacity (MW)
Bagel I	Plateau	1
Bagel II	Plateau	2
Ouree	Plateau	2
Kurra	Plateau	8
Lere	Plateau	4
Lere	Plateau	4
Bakalori*	Sokoto	3
Tiga*	Kano	6
Oyan*	Ogun	9
		TOTAL 39

Note:* indicates the need of plant rehabilitation

The success of rural electrification in Nigeria is closely linked with energy-mix option, most especially with renewable energy resource like small hydropower, and adoption of off-grid systems in the relevant rural areas. Akhator et al. [18] and Oyedepo [19] emphasize that decentralized off-grid energy solutions would significantly increase electricity availability as well as accessibility in the country. Yamusa and Ansari in [20] analysed the condition of rural electrification in Nigeria to provide viable solutions for the development and provision of energy to the local communities. Results from such works will go a long way to reduce the problems of electricity shortages in the rural areas. The work suggested and recommended that the Nigerian energy sector be diversified to incorporate and use the renewable energy sources that are readily available in the country to provide reliable electricity to the Nigerian rural populace. On the other hand, Azimoh & Mbohwa in [21] studied and explored the use of available renewable energy resources at eleven locations in different regions of Nigeria for optimal generation of energy in contribution to the Nigerian energy matrix. Three renewable energy resources: solar, wind, and hydro were investigated and fossil diesel as well. The study established that most places in all the six geo-political zones of the country are best suited for mini-grid systems. However, overwhelming majority of the places is only connected to the national grid. This study clearly outlines the important role that off-grid systems can play in rural electrification of Nigeria where SHP can be exploited as source. This fact is also reflected where Nigerian government provide both financial and technical support to developers of off-grid renewable energy projects of priority [22].

V. Conclusion

A comprehensive review of small hydropower development in rural areas of Nigeria and off-grid systems was carried out. The study has succeeding in reporting current works and major researches that were conducted at potential sites for small hydropower development and the use of off-grid systems. The studies under review have covered most regions out of the six geo-political regions in Nigeria. Small hydropower potential showed that theoretical electrical power range (5.13-5000 kW) is enough to cater for an average rural community in Nigeria and this is achievable in many locations if identified SHP sites are developed. The creation of decentralized off-grid networks at potential sites would significantly increase electricity accessibility in rural Nigeria. Substantial percentage of identified potential sites is still not harnessed. Although, some works are on-going and unreported, there still exist huge opportunities for investment and electricity generation in small hydropower systems regarding rural electrification in Nigeria.

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