Using Decentralized Renewable Mini-grid to Tackle Nigeria's Rural Energy Problems

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Abstract- The aim of this paper is to discuss the potential of decentralized, renewable mini-grid to solve the Nigerian rural energy problems. According to the World Bank, about 80 million Nigerians living in 8000 villages across the country lack access to electricity. Many of these villages are fortunate enough to be in proximity to indigenous renewable energy resources such as hydro, solar, wind, etc. and as such there is huge potential to deploy renewable energy technology in the design and construction of a low voltage electrical network. In many places due to remoteness and cost, it is unlikely that a main grid connection will ever be established. For Nigeria to achieve its millennium development goals, she must address urgently, the energy needs of the people, especially those at the rural communities. This will lead to economic growth in the rural region and thus the driving force to attaining rural community and sustained national development which is in line with the present Sustainable Development Goal, SDG of United Nations Development Program.

Indexed Terms- Developing countries, Economic growth, rural electricity, Renewable energy resources/technology, Sustainable development.

I. INTRODUCTION

Improving access to modern energy services in rural areas in developing countries remains a major development priority. While many countries continue to pursue ambitious and often challenging grid connection programmes, there is increasing interest in *decentralized generation (DG)* and distribution through mini-grids. These are defined here as a power source of less than 3MW (diesel, hydro, solar, biomass, hybrid) supplying a local distribution grid connected to domestic, business and institutional customers in the locality [1].

The Nigerian population is above one hundred and eighty three million [2] and about 55% of the population has no access to grid-connected electricity. Access to electricity in the rural areas is about 35% and about 55% in the urban areas [3]. Nigeria is the biggest and most attractive off-grid opportunity in Africa. It has the largest economy in Sub-Saharan Africa (GDP of $405 billion), a population of 180 million people, and flourishing growth (15 per cent a year since 2000). A significant amount of the economy is already powered largely by small-scale generators (10–15 GW) and almost 50 per cent of the population have limited or no access to the grid. As a result, Nigerians and their businesses spend almost $14 billion annually on inefficient, polluting and noisy generation that is expensive, and suffers from poor quality [4].

II. ISSUES WITH GRID EXTENSION

The existing system is only capable of delivering about 5,300MW (out of the total installed capacity of 12,500MW) of power. This is as a result of the country's current weak transmission infrastructure which is majorly radial. This means that it is a single path of transmission with a power source at one end. This implies that any fault in the path could potentially lead to a collapse of the transmission network. The issue with the transmission has been estimated to reduce the power generation capacity by a total of about 263MW. Although, the Transmission Company of Nigeria plans to upgrade the system to a capacity of 11,000MW by 2020 (subject to adequate funding and completion of projects planned for implementation); the transmission infrastructure in its current state, without an upgrade and improved technology, is unable to accommodate the estimated increase in generation by 2020 [5].

The benefits of electrification are well known and the demand for electricity service is widespread. But, because established utilities have often been pre-occupied with meeting the needs of the vocal and economically attractive urban areas and with maintaining existing systems, many have been unable to address the need of the rural villages [6].

III. CENTRALIZED VS DECENTRALIZED POWER

Centralized power generation has been the dominant approach to electrification in developed countries over the last century since the development of improved generation technologies such as large-scale steam turbines; the introduction of transformers and high voltage lines using alternating current [7]. A similar centralized approach has been followed in many developing countries. In post World War 2 Africa, for example, centralized electricity generation was seen as a precondition for development, with the delivery of electricity and infrastructure paving way for economic growth. This approach overlooked constraints such as dispersed population, low purchasing power and limited potential for load growth [8]. The main key variables in determining the cost of grid extension-comprising installation of high or medium-voltage lines, substation(s) and a low-voltage distribution are;

- the size of the load to be electrified,
- the distance of the load from an existing transmission line, and
- the type of terrain to be crossed.

Due to the lack of critical mass, the low potential electricity demand and the, usually, long distances between the existing grid and the rural area, the costs of electrifying small communities through grid extension are very high and therefore, not economically viable. The lack of local technical and management personnel and the high transmission losses are also deterring factors playing against this solution [9].

IV. OVERVIEW OF ENERGY RESOURSES IN NIGERIA

Nigeria with a land mass of about 924,000km^2 and an Atlantic shoreline of about 1000km is one of few developing countries blessed with sizeable primary energy resources. She is endowed with significant renewable energy resources including large and small hydroelectric power resources, solar energy, biomass, wind and potentials for hydrogen utilization; and development of geothermal and ocean energy. Table 1 presents some of Nigeria Energy Reserves/ Potential.

However, the country's current power sector planning process mainly favours conventional centralized gas fired generation. By 2020, this is set to comprise 74% of the country's total electricity output. Any positive result from the current geological surveys of the country will hopefully reinforce the sufficiency of these reserves for meeting the Nigerian domestic energy requirements [11].

V. EXPLOITING RENEWABLE ENERGY RESOURCES

One way to increase the power generation and per capita consumption of Nigeria is by installation of small or mini-grids for rural or remote areas since they are very far from the central utility. This can be achieved by using the available alternative resources of energy at the disposal of such centers, which are numerous. These alternative sources of generating electrical energy are called *Renewable Electrical Energy* and it refer to electric energy sources that do not result in the depletion of the earth's resources. The technologies involved in generating electricity from these natural sources are called *Renewable Energy Technologies, RETs.*

There are three main attributes of RES: free availability, allowance for modular technology and emission free. Therefore, developing countries must open a wide access to technology for the utilization of their indigenous RES .One of the greatest problems in utilizing renewable energy sources is their low density of power and intermittent nature depending largely upon local site and unpredictable weather conditions [12]. We will have a brief overview of the popular RES and RETs.

Resource	Reserves	Reserves (Billion toe*)	% Fossil
Crude oil	33 Billion barrels	4,488	31.1
Natural gas	4502.4 Billion m^3	3,859	26.7
Coal and lignite	27 Billion tons	1,882	13.0
Tar sand	31 Billion bbl* oil equivalent	4216	29.2
Subtotal (Fossil Fuel)		14,445	100.0
Hydropower large scale	10,000 MW		
Hydropower small scale	734 MW	Provisional	
Fuel wood	13,071,464(forest land)	Estimate	
Animal waste	61 Million tons /year	Estimate	
Crop residue	83 Million tons/year		
Solar radiation	3.5-7kWh/m^2/day		
Wind	2-4 m/s (Annual average)		

Bbl= barrel; Toe = tons of energy

a) Hydro power:

I According to the latest report, the global installed hydropower capacity increased from 896.9 Gigawatts (GW) in 2006 to 1,072.1 GW in 2011, and is expected to climb to 1,443 GW by 2020, thanks to support from governments around the world. Small hydro power, SHP has emerged as one of the most favored and promising solutions due to its reliability and affordability. Small and mini hydro facilities are gaining importance as their effect on the environment, and national budgets, is less substantial. The construction of SHP plants does not disturb the local habitat and the building of large dams and reservoirs is unnecessary, thereby avoiding issues of deforestation and submergence.

SHP plants are consequently much quicker to construct and also offer higher rates of return due to the low capital investment and operational and maintenance costs. Their implementation also carries positive social benefits as they encourage community participation and capitalize on local skills for plant construction. China is the biggest SHP market globally, accounting for 55.3% of the cumulative installed capacity in 2011. China has installed 59 GW of small hydro and is expected to take the lead among small hydro countries. China is followed by India and the US, with 9% and 6.9% of the SHP installations, respectively [13].

Although there may not be any international consensus on the definition of small hydropower, an upper limit of 30 MW has been considered. Thus, 30 MW has been adopted as the maximum rating under this dispensation. Small hydro can further be subdivided into mini hydro (<1 MW) and micro hydro (<100 kW). Thus both mini and micro hydro schemes are subunits of the SHP classification.

To determine the potential power of water in a river it is necessary to know the flow rate (Q) in the river and the available head (H) in meters. The flow of the river (m^3/s) is the amount of volume of water (m^3) which passes a cross section of the river in a given time (s).

The head is the vertical difference, in meters (m) in level the water falls down.

The potential power (P) available is given by the expression below:

$$P = Q * H * \rho * g \qquad \ldots (1)$$

…(1)

… (1)

Where ρ is the density of water, measured in $kg/m^3$and g is the acceleration due to gravity in ms^{-2}. Equation (1) can be re-written as: $P = Q * H * 1000 * 9.8W$ …(2)

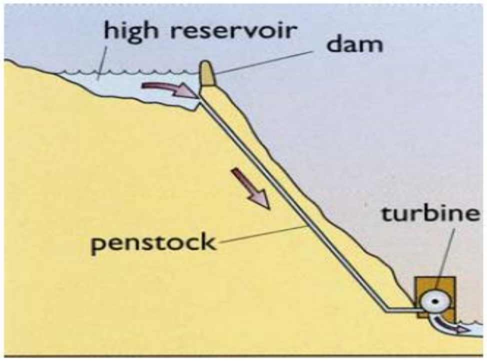

Fig. 1: - Typical Hydro power installation [14].

b) Solar and Photovoltaic technology:

Here, electricity is generated from solar energy (Sun) through photovoltaic materials (cells or modules) that converts sunlight directly into electricity. The knowledge of the amount of solar radiation in a given location (area) is essential in the field of solar energy physics. This in effect helps one to have a fair knowledge (idea) of the insolation power potential over the location [15]. Figure 2 shows the solar radiation in Southern Nigeria.

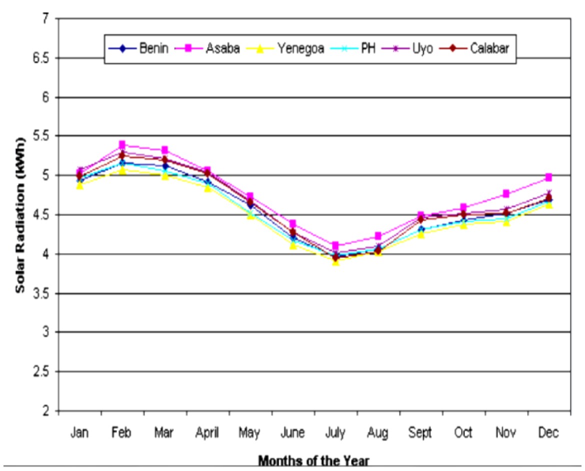

Fig. 2: - Monthly solar radiation in Southern Nigeria [16]

A photovoltaic system consists basically of the module which converts the solar energy to direct current (DC) electricity, the battery which stores the DC electricity for use when the solar radiation is either poor or non-existent, the charge controller which regulates the charging and discharging of the battery to preserve its life, the inverter which converts the DC from the modules or battery into alternating current (AC), wires, switches, relays mounting structures etc are all important in PV installation.

The expected energy consumption in Watt-hour per day of the location is derived using the following expressions:

$$E = n * P * T(Wh)$$
…(3)

(3)

Where:

E = Energy demand per day

n = Number of appliances

P = Power rating [W]

T = Duty cycle [h]

c) Wind energy:

Wind energy has been used for pumping water and milling grain for hundreds of years. More recently, wind energy has also been used for electricity generation. Wind turbines are now used for large-scale energy delivery, and can also be effective as small-scale remote applications. Developing countries can take advantage of wind power on a small scale, both for irrigation (wind pumps) and for generation of electricity [17].

Unlike the trend toward large-scale grid connected wind turbines seen in the West, the more immediate demand for rural energy supply in developing countries is for smaller machines of up to about 60 kW. These can be connected to small, localized micro-grid systems and used in conjunction with diesel generating 14 countries is small, the main area of growth being for very small battery charging wind turbines (50 – 500 Watts). Other applications for small wind machines include water pumping, telecommunication power supplies and irrigation [18].

The power in the wind is proportional to the cube of wind velocity. If the wind speed doubles, therefore, the power in the wind will increase by a factor of eight.

$$P = \frac{\rho * A * v^3}{2} \qquad ...(4)$$

Where P is the power, ρ is density of air (kg/m^3), A is the swept area (m^2), and v is the wind velocity (m/s).

IV. GRENEWABLE LOCAL GRID

Mini-grids can be an important alternative to or enhance the effectiveness of central grid extension to increase access to reliable electricity services in developing economies. Mini-grids are defined as one or more local generation units supplying electricity to domestic, commercial, or institutional consumers over a local distribution grid. They can operate in a standalone mode and can also interconnect with the central grid when available.

Although mini-grids can use diesel generators, renewable energy-based mini-grids (henceforth referred to as RE mini-grids) use electricity generation technologies that utilize locally available renewable energy sources like solar, wind, biomass, and run-of-river hydro, thus avoiding local and global pollution.

These generation technologies include solar photovoltaic and wind turbines with battery storage, biomass gasifiers and biogas digesters with internal combustion engines, micro and mini-hydro turbines, and hybrid systems (a combination of more than one generation technology). Due to their low or often zero fuel costs (except potentially in the case of biomass-based systems).

RE mini-grids can be more cost effective than those utilizing diesel generators or kerosene based lighting. The latter have little capital expenditure, but have relatively high fuel costs, volatile prices, and logistic limitations. RE mini-grids have distinct advantages over central grid extension and other decentralized energy options in providing access to reliable and affordable electricity.

V. ADVANTAGES OF THR MINI-GRID

RE mini-grids have distinct advantages over central grid extension and other decentralized energy options in providing access to reliable and affordable electricity. The following advantages are highlighted:

- Compared to central grid extension, RE mini-grids can be less expensive due to lower capital cost of infrastructure (depending on distance) and lower cost of operation by avoiding transmission and distribution losses [19].
- In countries with power shortages, electricity supply through the central grid, especially in rural areas, may not be reliable. In such regions, RE mini-grids that can be designed and operated effectively, can be more reliable than the central grid in providing electricity access and can ensure local energy security.
- Mini-grid developers have the potential to access capital beyond the traditional power sector, and may be able to provide quicker access to electricity than central grid extension that may be prone to bureaucratic hurdles and slow implementation.
- Unlike other decentralized energy options like solar home lighting systems and off-grid lighting products, mini-grids (depending on their size) can provide electricity to not only residential loads like lighting and phone charging, but also to commercial loads like mills and oil presses.
- RE mini-grid developers have strong incentives to pursue demand-side management, to keep capital cost of generation equipment low.
- Development and operation of mini-grids can create local jobs.

However, it is important to note that the design of a local mini-grid system requires the services of specialist who are capable, first of all, of estimating overall demand and how it will evolve, the local energy sources, and the future user’s ability to pay. Then they must define all the components of the system, production, transport, distribution and use [20].

VI. VARIOUS LOADS

Since the power demand of a house or a village or even a remote urban area is different at different time span, guaranteed power supply from a single decentralized power system may not be economical because of high initial investment and low load factor. Figure 3 shows a typical electric demand load curve in a village in developing countries. Most villages are characteristically agriculture oriented and have little or no commercial and industrial activities.

Energy consumption, particularly electrical energy, is very low. The base load is therefore, relatively little as compared with intermediate load and peak load. The peak load is mostly for lighting purpose and last only for maximum 2-3 hours in the evening The energy consumption/needs of the rural community are categorized into three groups; household, commercial and community conveniences (social services) consumption. Household energy consumption in most rural communities is mainly used for the basic functions of the home: lighting, entertainment (radio, video player and television).

The previously mentioned end users-lighting and entertainment- are very attractive and are most popular initial uses of electricity in most rural settings. However, if a mini-grid project is to pay for itself and to bring increased socio-economic benefits to the community, it often is necessary to judiciously incorporate productive, income-generating uses in the load mix. Many such uses, such as agro-processing equipment, refrigerators, water pumps, and metal working equipment require motors as the source of motive power [21].

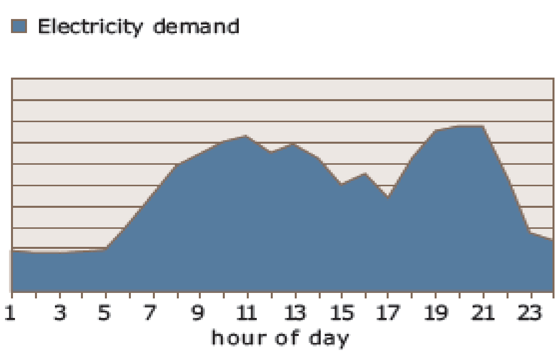

Fig. 3: - Typical load profile for rural setting [22].

VII. CONCLUSION

Consistent, economical, affordable and clean supply of energy in Nigeria is a must for a sustained national development and is indeed vital in the fight against hunger and poverty. A large number of Nigeria's citizens are presently denied access to energy. Coincidently, most of these people are residents of rural communities which also happen to be the poorest regions of the country. Mini-grids with distributed renewable energy system will be an important option to increase the access to reliable electricity for rural and remote area applications. The designed mini-grid is expected to cover the region's load and cater for the needs of the community. This will be the driving force to attaining rural community progress and indeed a sustained national development.

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