Nigerian Research Journal of Engineering and Environmental Sciences 5(2) 2020 pp. 835-854

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Review Article

Microgrids: A Decentralized Alternative for Rural Electrification in Nigeria

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ARTICLE INFORMATION

Article history:
Received 03 Sep, 2020
Revised 13 Nov, 2020
Accepted 17 Nov, 2020
Available online 30 Dec, 2020

Keywords:
Decentralized
Micro grid
Rural electrification
Off-grid
Power management
Renewable energy

ABSTRACT

Poor electricity services remain a major obstacle to growth in Nigeria, as inadequate and epileptic power supply undermines investment opportunity, economic growth, social and infrastructure developments. Centralized power generation, transmission and distribution system operations in Nigeria can no longer deliver competitively cheap and reliable electricity to remote customers on and off the national grid. Anticipated development in generation with a balanced combination of on-grid and off-grid power projects is very achievable in Nigeria. A balanced approach could potentially lead to an accelerated journey to full electrification in the country. This would in turn result in a significant boost of the country's economy, as power has been proven to be an enabler of other sectors of the economy. This paper presents micro grids as a decentralized alternative for rural electrification in Nigeria. The paper reviews the electrification status in Nigeria, power management of micro grid and prospect of renewable energy for rural energy provision. The benefits, challenges and future prospects of micro grid are also discussed. Implementation of decentralized micro grid across 774 local governments of Nigeria with five (5) micro grids installed in each local government will not only improve the wellbeing of Nigerian rural dwellers, but also enhance Nigeria's energy and economic prospects for potential global investment.

1. INTRODUCTION

Electricity is an essential contributor to the well-being of people and society (Sambo, 2005). It is essential and vital to meet man's immediate needs as a secondary source of energy to improve living standard and way of life, as well as boost society's socio-economic development. Its economic relevance to the development of any country cannot be over-emphasized. This can easily be observed in the per capita consumption, which can also serve as a further indicator of the citizenry's standard of living (Johnson, 2017).

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5(2) 2020 pp. 835-854

This is shown in a quick comparison of developed countries such as the United States of America, Australia, Germany and Japan with electricity consumption per capita of 12,947 kWh/capita, 10,218 kWh/capita, 7,138 kWh/capita and 7,753 kWh/capita respectively; and less-developed countries like Bangladesh, Cambodia, Nigeria and Myanmar with per capita electricity consumption of 280 kWh/capita, 206 kWh/capita, 155 kWh/capita and 152 kWh/capita respectively (Choy, 2010).

Presently, 160 million people in South East Asia have no access to electricity. Thailand is 99.3% electrified but remote island resort and mountainous communities and national parks are still in need of a steady off grid electricity supply, Indonesia has more than 80 million people without electricity, mostly in the more sparsely populated islands outside of Java and Sumatra. In Vietnam, 3 million people in 1100 mountainous communities are excluded from the government's grid extension plans. In Malaysia, 10 to 20% of the population in Sabah and Sarawak remain disconnected from the national grid (Choy, 2010). According to International Energy Agency IEA (2015), 1.2 billion people lack access to electricity; that is, 17% of the world population. This includes over 400 million in India and about 620 million in Africa with consumption per capital less than what is needed to keep a 50-watt light bulb glowing continuously (Schnitzer et al., 2014).

However, India is making great progress to overcome this problem as they are ambitious of becoming a developed nation (Elusakin et al., 2014). Sub-Saharan Africa is the most electricity-deprived region worldwide in terms of the total number of people. More than 45% of these people are without electricity and around 80% are in rural areas (USAID 2014, IEA, 2015). Access to electricity in selected sub-Saharan Africa countries is shown in Table 1 while Figure 1 depicts reliability of grid electricity in connected households in Africa (Blimpo and Cosgrove-Davies, 2019).

Table 1: Access to electricity in selected sub-Saharan Africa countries (IEA, 2015)

Country	2006		2030	
	Population without access (million)	% of population	Population without access (million)	% of population
Angola	12.9	88	18	59
Cameroon	14.2	78	17	64
Chad	10.1	97	18	92
Congo	2.9	78	4	68
Cote d'Ivoire	11.6	61	14	50
Equatorial Guinea	0.4	73	0.4	50
Gabon	0.9	70	1.2	66
Mozambique	18.6	89	22	72
Nigeria	76.6	53	88	29
Sudan	26.9	71	30	51

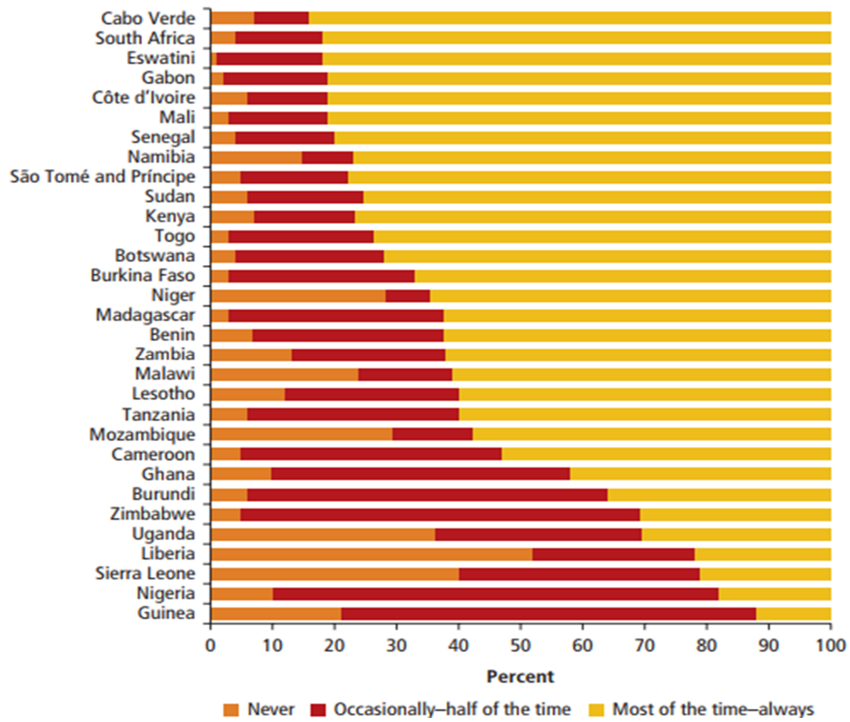

Figure 1: Reliability of grid electricity in connected households in Africa

2. ELECTRIFICATION STATUS IN NIGERIA

Energy contributed greatly to the transformation of the world and provided comfort to the human race. Nigeria has vast and varied energy resources, both renewable and non-renewable (Shaaban and Petinrin, 2014). According to the IEA 2015, the country is also the largest economy in Africa with a gross domestic product (GDP) of about $531.8 billion. However, Nigeria still faces grave energy deficiency issues, with energy supply falling short of energy demand. The 4,500 megawatts (MW) of electricity generated for the national grid was grossly inadequate for a leading African economy like Nigeria with a population of over 183 million people as at 2015 (Sulaimon, 2016). The application of technology for industrialization is a key to enthroning sustainable economic growth and development. The off-grid microgrid (MG) rural electrification is to help reduce the wide gap in the energy sector in Nigeria.

In spite of the huge investments on the energy sector since the privatisation of the Power Holding Company of Nigeria (PHCN), about 75% of the Nigerian population still lack access to regular electricity supply (Iledare, 2015). Despite statistics indicating that 45% of the Nigeria population is currently connected to the national grid according to The Nigerian Association of Energy Economists (NAEE), regular supply is still restricted to just about 25% of the population. Most of the people with access to electricity are found within the urban areas, thus leaving citizens in the rural areas with less access to the electricity grid (Obasi, 2015).

It is estimated that the nation has as much as 90% shortage in electricity supply while access to electricity is practically zero in off-grid areas where some 50% of the country lives (Iledare, 2015). Even in on-grid areas, power outages are still a frequent event and this has continued to pose serious limitations to economic development. There is obvious inequity in access to electricity based on location, and levels of income. Some of the factors for this pitiable state of lack of access to electricity are endemic corruption, inconsistent government policies, poor assets maintenance, lack of transmission infrastructure and inadequate gas supply to thermal generation plants.

The maximum power generated in Nigeria since 2015 at a single time is less than 4000 MW. Normally, it fluctuates between 1,400 MW to 2,800 MW. The City of Edinburgh, United Kingdom, consumes in excess of 2,700 MW at any given time. It is needless to express that South Africa, with a population of over 40 million people, produces around 50,000 MW of electricity. Privatisation has done very little to bring about the necessary improvement in the power sector (Adamu, 2016). There is a severe electricity paucity in Nigeria and the causes of these paucities are related to financial, structural issues, and socio-political which cause the power sector in Nigeria to be recording high energy losses (Muhammad, 2012).

3. BACKGROUND OF NIGERIAN ELECTRICITY SUPPLY INDUSTRY (NESI)

The dawn of electricity generation in Nigeria can be dated back to the end of the 19th Century, in 1898. Fifteen years after the introduction of electricity in England, the first electricity power plant with total capacity of 60 kW was installed in Marina, Lagos (Awosope, 2014). However, the Nigerian electricity industry can be said to have formally started operations in 1929 when the first utility service company began with the construction of a hydroelectric power station at Kurra, Plateau State (Ighodalo, 2006). From that period until 1950, electricity generation in the country was in the form of individual/unit facilities with a few undertakings being carried out by the then government Department of Public Works, others by the different regional municipal authorities and local native authorities.

In a bid to integrate the rapidly expanding electricity power industry and make it more effective, the Electricity Corporation of Nigeria (ECN) was formed in 1951 (Monyei et al., 2018). This brought all power undertakings and the electricity department in the country under the reins of one state-controlled body. This also started a flurry of developments in the sector such as the commissioning of a four-unit coal powered station in Oji in 1956, the establishment of the Niger Dam Authority (NDA) in 1962 to develop the hydropower potentials of the country; and the construction of the first 132 kV transmission line linking Ijora Power Station in Lagos to Ibadan Power Station in Oyo State - a distance of over 60 km in 1962 (Adenikinju, 2005). Thereafter, the Kainji Hydropower station was commissioned in 1968.

The ECN and NDA were merged in 1972 by the Federal Government of Nigeria (FGN) to form the National Electric Power Authority (NEPA) with the statutory function of developing and maintaining an efficient, well-coordinated and economical system of electricity supply throughout the country. NEPA had complete monopoly/control of all commercial electricity supply in the country but it did not inhibit individuals who wished to purchase and run thermal plants for domestic/private use from doing so (Oyedepo, 2012). The privatization process of NEPA began in 1999 with reforms in the sector due to its failure to satisfactorily perform its statutory function of electricity provision to the citizenry. To address the double issues of NEPA's poor operational and financial performance, the FGN amended the then prevailing laws (Electricity and NEPA Acts) in 1998 to remove NEPA's monopoly and encourage private sector participation. Consequently, FGN established the Power Holding Company of Nigeria (PHCN) – the initial holding company and subsequently unbundled it into eighteen (18) successor companies. PHCN accounted for about 98% of the total electricity generation in Nigeria (NERC, 2011).

The changes in nomenclature of the power sector have not brought any improved performance. Instead, the condition of power supply is getting worse as a result of unfaithfulness and incompetence. In 2013, the Nigeria government hurriedly sold PHCN to 'designated private investors' who purportedly bought the several stages of the relay-like PHCN for peanuts. These investors, who have since been in-charge of power output control in Nigeria, have even made the condition unbearable. Nigerians are worse off now than when it was a totally government enterprise, an aberration more aching to all Nigerians (Adamu, 2016).

Presently, there are fifty-eight (58) on-grid generating licensees expected to supply the grid 26,423.2 MW of electricity – this being their total installed capacity when fully completed and all tied-in. Another three (3) licensed for embedded generation within the distribution network with a total embedded generation capacity of 133 MW and nineteen (19) off-grid licensees with a total installed capacity of 312.5 MW (TCN, 2014). The nation's transmission grid network made up of seventy-two (72) 330 kV circuits and one hundred and eighty-five (185) 132 kV circuits is a government-owned monopoly. It has a total combined capacity of 19,427.5 MVA, twenty-seven (27) 330 kV substations and one hundred and fourteen (114) 132 kV substations (Etukudor et al., 2015). It is controlled and operated by a single government-owned system operator: The National Control Centre, Oshogbo. While the nation's distribution network is being handled by fourteen (14) distributing companies (DISCO) directly responsible for the supply and metering of electricity to the consumers (Odeku, 2013).

4. RURAL COMMUNITIES IN NIGERIA

Indigent people living in the rural communities face a major challenge in trying to achieve their social obligations and development due to lack of access to utility electricity supply (Raman et al., 2012). Access to electricity is crucial for poverty alleviation and promotion of economic growth. Rural communities' electrification in developing countries helps to improve the quality of life of the dwellers. It increases productivity and supports education. It also discourages rural dwellers from migrating towards urban areas (Kumar and Banerjee, 2010). Nigerian is undergoing an energy crisis which brought irregular and excessive load-shedding in most parts of the country with increased energy cost per kWh and a lack of micro financing options for communities with low electrification rate. Moreover, rural electrification projects involving MGs are non-existent in Nigerian due to many security concerns from investors (Dada, 2014).

Rural areas are the worst hit in terms of poor access to electricity supply, particularly the off-grid communities, which have always been without electricity supply and have resigned their fate to the use of oil lamps, kerosene lanterns, and other types of unhealthy and dangerous sources of light for daily living. This development is inimical to socio-economic development of the country as it has created an atmosphere that is not conducive for Micro, Small and Medium Enterprises (MSMEs), which are the drivers of the country's economic growth.

In many of the rural communities, the conventional approach to serve them with electricity is to extend the utility grid. However, grid extension to rural and remote areas is not a cost-effective solution and it is inefficient due to a combination of capital scarcity, insufficient energy service, reduced grid reliability, extended building times and construction challenges to connect remote communities (Wiese, 2007). Moreover, the national electricity grid is not intended to accomplish the growing demands of the growing population and may be disrupted by new customer. Decentralized delivery options and alternative electricity supply need to be considered. Therefore, MG technology will be more cost-effective to supply electricity to those communities by means of RE sources available locally. The integration of RE generations in MG is the only practical solution to meet rural electrification needs (Navigant, 2014). The more remote the location, the more competitive MGs get since it's much cheaper to produce electricity locally than to extend utility grids into the mountains or through the forests (Giri, 2015).

5. MICROGRID TECHNOLOGY

The electric power sector is continuously evolving globally. The current development is the transition from centralized to decentralized energy generation technologies. This is constantly being demonstrated in different parts of the world both in autonomous and grid connected modes in form of MG (Peng et al., 2009).

A microgrid is a cluster of interconnected micro-sources that are referred to as distributed generations (DGs), loads and energy storage systems that cooperate with each other to be collectively treated by the grid as a controllable generator or load (Shahidehpour and Khodayar, 2013; Dada, 2014; Petinrin et al., 2015). It should be capable of riding through between grid-connected and autonomous modes if necessary. MG serve as a key alternative for meeting people's energy needs where there is no access to the electricity grid. A MG can be strategically located at any position in a power network, particularly at the network system for grid reinforcement, thereby eliminating or deferring the need for network upgrades and improving system reliability, efficiency and integrity (Alam and Bhattacharyya, 2016). It will also boost community welfare and education and increase income generation activities.

The design also determines not only the quality of the services provided, but also the price of the energy produced to the users. A technique which integrates load modeling, generator location, system sizing, and loss estimation to get the efficient and cost-effective design of off-grid MG was proposed by Phrakonkham et al. (2010). The integrated technique is described in a flow chart shown in Figure 2. This comprises sizing the system components, identifying the optimal source location, estimation of the load on the system, analyzing the distribution network and estimating the voltages and currents.

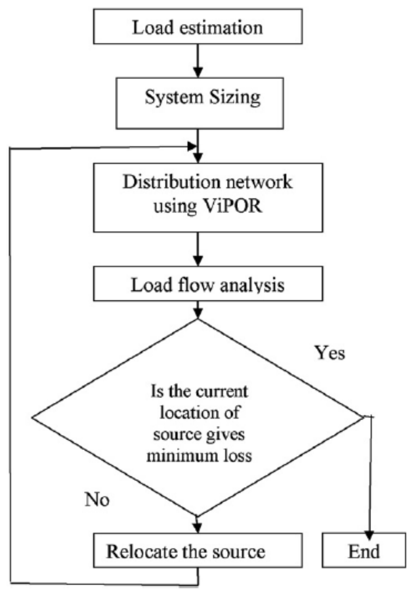

Figure 2: Integrated design technique for off-grid MG (Phrakonkham et al., 2010)

Priority should be given to sitting and sizing the MG appropriately and also to energy efficiency. Energy efficiency is very important regardless of the choices since it can influence dramatically the energy load, and therefore the amount of energy required. This will impact financial viability of the project and the investment costs. The first energy policy should be on supply and demand side management. In many rural areas, there is a propensity to concentration on the reduction of short-term investment costs, which will require on-going awareness rising and efforts to support local availability of energy-efficient appliances.

The MG technology has been found very appropriate and relevant for the rural communities. Countries with many islets have been exploiting this MG system due to the difficulties attached to operating a centralized utility grid. Pacific countries and East Asia have recorded a breakthrough in this technology. Nigeria has little islets (such as Brass in Bayelsa, Bonny in River State, Bishop Kodji and Banana in Lagos) and many villages that are sparsely distributed specifically in the northern part of Nigeria. This necessitates the need for taking sort in MG technology.

At present, only 10% of rural households in Nigeria have access to electricity. Efforts are being made to alleviate the condition of the rural dwellers. The Nigerian Energy Commission (NEC) and the Solar Energy Society of Nigeria (SESN) have been tasked with generating standalone solar-powered solutions for the remote rural communities. The nation is considering further development of the hydropower resources and other RE sources such as biomass, solar and wind to close the generation shortfall and foster economic growth. The level of deployment of MG requires serious attention to salvage the nation from a looming energy crisis. A lot of new RE sources would soon come upstream, such as, the 40 MW Gurara dam in Kaduna State, the 40 MW Kashimbilla dam in Taraba, 10MW wind farm in Katsina and 30 MW phase one of Kudendan dual fired plant in Kaduna-State. On the new Rural Electrification Implementation Strategy (REIS), FGN has changed her focus from grid extension to a more decentralized format that would emphasize MG to be fed from RE sources, which would be off-grid.

The MG configuration represents the energy distribution architecture from the generating locations to consumers and eventually the interconnection between several locations and several consumers. As on-grid MGs will help in strengthening the existing grid, the off-grid MGs will help supply the rural communities in most economical way thereby pave the way for private investors to participate in the electrification of the rural communities in Nigeria. It is therefore important for the country to move with the rest of the world by focusing on how these technologies can be implemented to modernize her ageing electricity infrastructures. Evidence from successful rural electrification projects shows that, once electricity becomes available in a community, wealthy households and upper middle class are the first to adopt it. But if the rural electrification project focuses on promoting electricity for poor households-through lifeline rates and low connection fees, the rate of electricity adoption grows significantly, even among the poorest households.

6. HYBRID-MICROGRID SYSTEM

Hybrid MGs incorporating renewable energy (RE) can be a cost-effective means of supplying reliable and affordable power to rural dwellers. However, such hybrid MG requires capacity building at every point of the MG project chain, and with every stakeholder. Capacity building work, from the commencement of the project to the system operation and the local social structures organization, must be factored into the timeframe and cost of the project development upfront for the sustainability of the investment (Blimpo and Cosgrove-Davies, 2019). Autonomous MG such as wind energy or photovoltaic (PV) systems, do not produce usable energy for considerable period of time during the year. This is due to relatively fickle cut-in wind speeds, and variable sunshine hours as regards to solar PV, resulting in underutilization of capacity (Deshmukh and Deshmukh, 2008).

The independent use of either solar PV or wind energy results in considerable over-sizing for system reliability. Mixing different technologies with different RE sources offers competitive advantages compared with using a single technology (Adaramola, 2012). Studies depicts that hybrid MGs are more reliable and cheaper than single source energy systems MG and the conceivable limitations and possibilities in the hybrid MGs have also been discussed in literatures (Nema et al., 2009; Ajao et al., 2011; Adaramola et al., 2012; Lena, 2013; Bertheau et al., 2015; Petinrin et al., 2015; Alam and Bhattacharyya, 2016). The combination of RE sources with a diesel/petrol generator has demonstrated to be the least-cost solution for rural areas as the merits and benefits of each technology complement each other (Hafez and Bhattacharya, 2012).

With decreasing PV prices, PV-diesel hybrid minigrids are attracting significant attention from institutions in charge of rural electrification and donor agencies - to mitigate fuel price increases, deliver operating cost reductions, and offer higher service quality than traditional single-source generation systems. The combination of technologies provides interesting opportunities to overcome certain technical limitations (Hafez and Bhattacharya, 2012). There is diverse geography in Nigeria which makes it difficult to connect utility grid to rural communities. RE has become an important alternative as a power provider in rural communities in supply side planning for MGs (Deshmukh and Deshmukh, 2008). Introduction of RE provides good prospect for effective energy decentralization and security to both rural and urban citizens. This could be carried out through DG, wind, biomass, solar PV, and the diesel operated hybrid-microgrid system.

Hybrid systems are basically a combination of two or more different but complementary energy supply sources at the same site. Hybrid systems offer relatively continuous electricity at an affordable price, even when one of the supply systems is shut down. Typical hybrid systems include a conventional generator power by diesel, for example, and a renewable energy source(s) including wind energy, solar PV or both, and energy storage such as batteries if needed (Nejabatkhah and Li, 2015). Standalone hybrid MG systems can provide for the daily energy services, such as lighting and cooking, for the rural and penurious rural communities in Nigeria. Although the previous proposed regulatory policies could promote the RE deployment in Nigeria, but, the FGN needs to take decisive initiatives in enhancing the deployment, development and application of RE resources and technologies in the national energy market. The incentives assigned for subsidies on petroleum and fossil fuel should be shifted to the development of RE, to make the technology affordable for impoverished rural communities.

Stimulatory measures such as adoption of a cost-effective electricity tariff; and encouragement of private sector participation to advance RE service provision among private and public investment are to be implemented as it is done in South Africa, Malaysia and Egypt. Strict energy polices need to be promulgated and enforced with adequate earmarked funding so as to save Nigeria from a possible energy crisis, that can render the rural communities in darkness in this modern age.

7. POWER MANAGEMENT OF MICROGRID

From a system-wise point of view, the overall efficiency of the power system can be increased with MGs by integrating larger amounts of DGs, including RE sources (Basu et al., 2011). This will enhance system reliability, minimise greenhouse gas (GHG) emissions and reduce system losses. However, the critical issue is proper management of the MG's generation and energy storage operation as well as its effects if connected to the utility grid (Katiraei et al., 2008). A MG balances its loads when operating in grid-connected mode by importing power from the utility grid it is integrated to. Nevertheless, it uses its own generation resources in standalone mode to supply power to the customers.

A MG thus needs a power and energy management (PEM) strategy to guarantee coordination between DG units and the main grid for reliability and economic operation (Petinrin and Shaaban, 2013). The main purpose of the PEM is to reduce MG's operating costs, as well as fuel costs if it has conventional generation, and cost of energy purchased from the main grid. The criteria required to meet such objective are (Montoya et al., 2013).

i. Load sharing among DGs to reduce the power losses in the system
ii. Considering factors that affect limits of DG units such as type of DG, environmental impacts, maintenance interval, and generation cost
iii. Preserving the power quality, harmonic distortion and voltage profile
iv. Improving the dynamic response, maintaining stability margin including restoring voltage/frequency of the system during and after transients.

The control and flexibility of MG is usually done through power electronic (Wiese, 2007). The main control functions for DGs, within a MG, are voltage and frequency controls, in addition to active and reactive power control. Control of dispatchable units can be carried out using definite reference values for reactive power support and real power dispatch. Energy storage is an essential constituent in MGs, since it can maintain the balance between generation supply and load demand at the instant of system separation. It also provides a 'firming' capacity for variable renewable generations (Schmitt et al., 2013). Electric energy storage is vital to enhancement the generators during low voltage transient on the MG or, when in standalone operation (Hamilton and Gulhar, 2010). However, a hybrid wind-PV energy system with demand response feature can produce a highly reliable source of energy that is suitable for MGs in the standalone mode, thus, reduces the energy storage required (Roney, 2013).

Where the output power must meet the total load demand, load/generation shedding can be done in MG standalone mode to maintain power balance. Hence, the operating strategy of a MG must ensure that essential loads of the MG receive service priority, whereas nonessential loads may need to be dropped; unless there is sufficient generation and energy storage provided in the MG to cover all needs. In practice, demand response control strategy can be applied on part of nonessential, controllable loads to reduce the peak load and smooth out the load profile. However, the non-controllable part of the noncritical loads is appropriate for load shedding (Petinrin and Shaaban, 2013).

8. MICROGRID AND RURAL ELECTRIFICATION IN NIGERIA

Rural electrification projects in Nigeria adopted the use of on-grid and off-grid system just like other countries. The choice of power generation (on-grid and off-grid) is determined by cost of connecting with the utility grid, security of the extension power line, geographical location of the communities, and availability of the energy resources in the environment. Most of the rural communities' electrification was connected on-grid.

MGs employ different generation resources that include diesel, wind, PV, biomass gasification and micro-hydro, as well as hybrid technologies such as wind-diesel, wind-PV and PV-diesel. Off-grid MGs which primarily has a link with the RE sources such as wind, solar, biomass and small hydro are pronounced in Nigeria like East Asia and Pacific countries (China, Japan, Solomon Island, New Guinea, Papua, etc). For example, it took Bangladesh over a decade with the World Bank, to install 1.4 million rural solar home systems as at mid-2012). Peru first phase of its national home electrification program took a half-million off-grid homes with PV (UNDP, 2016). The shortage of electric power supply, frequent vandalism of the transmission lines, high cost of connecting a remote rural communities on-grid, and challenge of maintenance of distribution equipment such as ring main unit (RMU) transformers require the provision of electric power through off-grid option for remote communities.

The erratic power supply by DISCOs in Nigeria has brought the urban dwellers that are supposed to have more access to the electricity to the same fate with the rural dwellers. This made some State Government in Nigeria to propose off -grid MG systems with the support of international organisation such as World Bank to supply electricity for some government services centers such as government house, Hospital, ICT buildings and some remote area within their states. No fewer than 200 off-grid houses in Obayantor 1 community, Edo State, have been provided with access to clean and affordable power supply courtesy of the Bank of Industry (BoI) and the United Nations Development Programme (UNDP) 24kW solar micro-grid scheme. This was aimed at giving rural communities the opportunity to take control of their energy generation and also pay for only the energy used (Clean, 2017).

The FGN proposed a 75 MW solar photovoltaic MG power plant in Katsina State, expected to be commissioned in 2017 but, the deadline was extended to 2019 as a result of the potential for additional socioeconomic and environmental impacts (Uduak, 2015). Unfortunately, the project is still ongoing. The MG power plant will sell power for a tariff of 11.5 US cents per kWh. This MG solar energy will be the largest of its type in Sub Saharan Africa (excluding South Africa) and will supply electricity for 1.1 million Nigerians. Apart from providing about 500 jobs for local people during the 12months construction period, about 40,000 new jobs will be created from the additional economic activity stimulated by the power plant. Presently, Renewvia Energy Corporation, an American firm, and Community Energy Social Enterprises Limited, a Nigerian company, have signed a Memorandum of Understanding (MoU) to deliver solar power to 25 rural areas across Nigeria using off-grid MGs. The rural areas are located in the Nigerian States of Ogun, Bayelsa, Osun and Ondo.

The off-grid MGs were expected to be operational by the end of the year 2017 and have a total capacity of 10 megawatts (Williams, 2016), but yet to be completed as at 2019 due to paucity of funds. Solar energy developer Phanes Group planned to develop three solar PV-MGs at three different sites in the North-West of Nigeria with a combined capacity of 300 MW. This is expected to contribute to Nigeria's goal to produce 2000 MW of power from RE sources by the end of the decade (Achugbu, 2012). An investigation into the rural community electrification projects carried out by Uduak, (2015) and Okeke, 2016 in Nigeria 36 states households and the Federal Capital Territory is depicted in Table 2. Although, mountainous, swampy and non-road worthy communities that could not be reached were not included.

However, it is pathetic, that most of the past off-grid MGs such as solar PV power generations became waste of resources due to lack of maintenance and subsequently discourage the Government commitment. One of such cases was Solar PV plant located at Onisowo village, Bishop Kodji Island, Lagos State. This colossal failure in the off-grid MG technology hinders further investment in the off-grid technology by some private investors and state governments in Nigeria. In the past years, only forty (Nejabatkhah and Li, 2015) solar PV off-grid power generation was put in use in Nigeria rural areas according the Rural Electrification Agency (REA) (Ige, 2013). This shows that Nigeria is yet to be involved in off-grid MG technology. In Malawi solar PV and biomass were used to supply electricity to poor subsistence-farming households and schools in 321 rural communities with better performance results. The MG technology which is anticipated to bring a basic amenity and as well electric power that will support the infrastructures such as health centers, ICT buildings, pipe-borne water and schools in rural communities had turned to mere experimental specimens.

The future of off-grid MG technology is yet to be defined in Nigeria. In spite of the support receive from the International communities on energy and relevant body for rural electrification, Nigeria is yet to have breakthrough in off-grid MG technology. Osun State of Nigeria claimed to have spent a lump sum of ₦1,059,427,861 on rural electrification for about seventy-seven (77) projects across the village within 2011 and 2013. However, the money was spent not on off-grid MG but on connection of the rural areas with utility on-grids and maintenance of bad distribution equipment (Faturoti, 2012; Omisore, 2015).

Many Northern States government of Nigeria were motivated to generate electricity through solar PV due to abundant solar PV energy resources in the region, however, the colossal failure in the project discouraged them from continuing with the off-grid technology. These failures were recorded in state like Nasarawa, Borno, Sokoto, and some Southern States like Lagos and Bayelsa. The Sokoto State project was abruptly terminated and the rural dwellers were advised to be patient until the state government has enough funding for utility on-grid connection which would cost roughly $22 million and take decades according to Alhaji Garba Umar Kyadawa, special adviser to the Sokoto State Governor on rural electrification (Akinbami, 2001). Unfortunately, the promise is yet to be fulfilled due to the economic recession of 2016.

Table 2: Household electrification rate by State (Uduak, 2015; Okeke, 2016)

Geographical zones and states	Household with electricity (%)	Household without electricity (%)	Missing (%)	No. of household surveyed
North Central	48.7	51.2	0.1	5,942
FCT-Abuja	77.7	22.0	0.3	361
Benue	22.1	77.9	0.0	1,365
Kogi	62.9	37.1	0.0	876
Kwara	90.6	9.1	0.3	617
Nasarawa	33.2	66.5	0.3	550
Niger	51.7	48.2	0.1	1,504
Plateau	36.3	63.7	0.0	669
North East	29.3	70.4	0.3	5,115
Adamawa	37.6	62.2	0.2	726
Bauchi	29.3	70.3	0.4	932
Borno	33.0	66.5	0.5	1,560
Gombe	48.1	51.8	0.1	464
Taraba	10.99	88.8	0.3	634
Yobe	18.1	81.7	0.2	799
North West	42.2	57.7	0.1	9,992
Jigawa	26.0	74.0	0.0	1,152
Kaduna	53.5	46.2	0.3	1,915
Kano	52.1	47.8	0.0	2,606
Katsina	31.3	68.5	0.2	1,257
Kebbi	44.4	55.6	0.0	1,069
Sokoto	38.9	60.9	0.2	898
Zamfara	29.1	70.6	0.3	1,096
South East	66.4	33.6	0.0	4,687
Abia	81.7	18.3	0.0	644
Anambra	88.1	11.8	0.1	1,050
Ebonyi	39.2	60.7	0.1	978
Enugu	55.4	44.6	0.0	920
Imo	69.9	30.1	0.0	1,096
South South	68.3	31.3	0.4	5,239
Akwa Ibom	68.0	31.8	0.2	892
Bayelsa	52.5	47.3	0.2	322
Cross River	57.4	41.4	1.2	848
Delta	78.3	21.6	0.1	946
Edo	82.4	17.5	0.1	702
Rivers	65.1	34.5	0.4	1,529
South West	81.1	18.8	0.1	7,546
Ekiti	92.7	7.3	0.0	376
Lagos	99.3	0.5	0.2	2,240
Ogun	72.0	27.9	0.1	1,355
Ondo	66.3	33.7	0.0	920
Osun	89.4	10.6	0.0	853
Oyo	66.6	33.3	0.1	1,802
Total	55.6	44.2	0.2	38,523

9. PROSPECTS OF RENEWABLE ENERGY MICROGRID FOR RURAL ENERGY PROVISION

Conventional grid was originally designed and constructed for one-way power flow from the generation system to the transmission system and further to the distribution system and finally to the end users. The literature identifies renewable energy potentials in Nigeria (Ohunakin, 2010; Newsom, 2012; Odinakadotnet, 2012; Oghogho, 2014; Shaaban and Petinrin, 2014; Okeke, 2016). Although, RE sources impose challenges to conventional grid management due to two-way power flow of electricity. Hence new smart solution required is found in renewable energy for MG technology. The objective is to move towards a more intelligent and active centralized generation with more intelligent transformers and substations to distributed generations.

In 2003 the FGN approved the National Energy Policy (NEP) to articulate the sustainable exploitation and utilization of all viable energy resources. The policy is hinged on private sector development of the energy sector. The key elements in the national policy position on the development and application of RE and its technologies are as follows (UNDP, DFID and World Bank; 2016)

i. To develop, promote and harness the RE resources of Nigeria and incorporate all viable ones into Nigeria energy mix.
ii. To promote decentralized energy supply, especially in rural communities, based on RE resources.
iii. To de-emphasize and discourage the use of wood as fuel.
iv. To promote efficient approaches in the use biomass energy resources.
v. To keep abreast of international developments in RE technologies and applications.

The US government launched a RE initiative called ‘Power Africa’ (PA) in 2013. The RE initiative is to work with private sector partners and African governments to mitigate hindrances that delay sustainable energy development in sub-Saharan Africa and unravel the substantial hydropower, solar, wind, biomass, geothermal and natural gas resources on the continent. The purpose of the programme is to increase access to electricity by adding more than 30,000 MW of more efficient and cleaner electricity generation capacity and 60 million new business connections and home across sub-Saharan Africa. The off-grid sub-initiative meant at extension of rural electrification and providing access to off-grid and small-scale technology in the PA (Akinyele and Rayudu, 2016). FGN and the US signed a Memorandum of understanding (MOU) on 24th July 2014 specifying commitments of the two countries in lieu of the PA programme implementation in Nigeria. Nigeria has high potential to harness energy from RE resources to meet rural energy needs according to Shaaban and Petinrin, 2014.

Policy makers and energy planners have identified off-grid energy systems as options for generating electricity for rural areas, around the globe. Such systems could either be fuelled by non-renewable or RE resources, but because of the issue of climate change and the compelling need for environmental sustainability, the global community is strongly advocating for eco-friendly energy technologies (Soyoye and Ayinla, 2016). Prospects for off-grid solutions in Nigeria includes potential to grow industrial clusters and small cottage industries, opportunity to expand and refurbish distribution networks of the DISCOs, off-grid solutions within a cluster of customers willing and able to pay present a viable investment opportunity for power developers. To avoid regulatory constraints, many state governments are looking to partner with investors to develop more off-grid projects than on-grid projects.

Off-grid solutions are also useful in Nigeria in view of some topographical or geographical challenges in the rural areas which have made it uneconomical to extend the grid to such areas. Most of the power plants in Nigeria are gas fired thermal plants. Given the current constraints with gas, off-grid power plants are able to take advantage of diverse and hybrid fuel sources like renewables (solar, wind, biomass) and because the power is not generated on-grid, transmission constraints with renewables are eliminated. Some variable RE sources for MG are shown in Figure 3. This would be particularly more useful in areas where there is limited gas supply, e.g., the northern part of Nigeria where solar, wind, and hydro sources are prevalent.

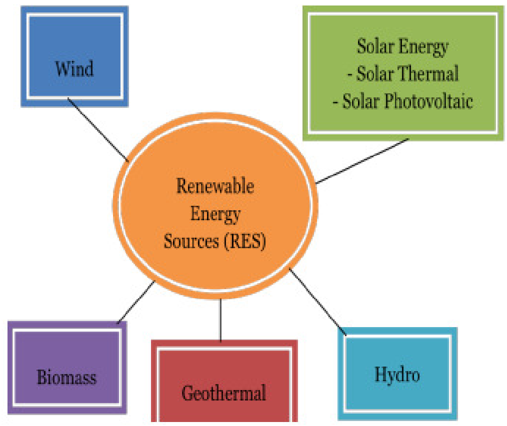

Figure 3: Some viable renewable energy sources for MGs (Iloeje, 2002)

Opportunities abound for the use of RE sources where electricity, mechanical or thermal energy power, is required. Such applications include electricity generation, domestic and industrial cooking and heating of gasses and liquid, thermal power plants, grid power supply and standalone power systems; lighting, irrigation, water purification and potable water supply; drying and processing of agricultural products, etc (Schnitzer et al., 2014). However, in view of certain characteristics of the energy sector in Nigeria and the qualities of the RE, in comparison to non-RE and conventional energy, greater prospects for RE integration exist in the rural sector of the economy.

Energy is a vital constituent for the socioeconomic development and rapid urbanization. Modern economic activities depend mainly on petroleum products and electricity. However, there is grave economic and demand capacity constraints in the extension of electricity grid to the rural communities. Rural community dwellers are famished, their center of energy demand is scattered and energy demand levels are low. While almost 81% of the urban dwellers have access to electricity, only 18% of rural counterparts are exposed to it. In addition, while the retail price of kerosene in rural areas is often higher, it can be purchased in some urban centers at pump price (Ikuponisi, 2004).

Micro-hydro systems, solar PV and wind have demonstrated more cost-effective on a lifetime basis, than diesel generators or utility grid in situations where loads are low and far from the grid. The dotted nature and low power demand levels of rural load centers suggest the use of decentralized and small-scale power supply systems to which micro-hydro systems, solar PV and wind and other RE sources are effectively suited. Thoughtful programs and policies are needed to identify and implement the above concepts in rural communities that are to be off-grid connected in the long term (15–20 years). A sustainable project implementation approach will necessitate the combined participation of the private sector, government, and consumers.

RE resources such as small hydropower (SHP), wind energy, biomass and solar PV are, in general, well distributed over Nigeria. The concept of Integrated Rural Village Energy Supply (IRVES) is established by the FGN to study the energy needs of rural community dwellers for different socioeconomic activities. This includes energy resources available to these communities, energy related environmental problems as well as the skills and trainability of its manpower. An energy demand and supply system for the rural area would then be developed with the available RE sources, to meet the identified needs in a sustainable way. Capacity building programs and post-project management will be provided to enhance sustainability. Key features of the post-project management arrangements are provision for community payment and participation in the management, by beneficiaries, of centrally provided energy services, to cover maintenance costs and operation (Odeku, 2012)

In addition, widespread implementation of modern RE microgrid technologies, with the appropriate government support, can deliver an excellent alternative to conventional firewood-based technologies; used largely by rural dwellers. Large scale implementation of solar cookers and biogas technology including the use of natural gas, kerosene and coal briquettes can minimise the share of fuelwood in the energy mix (Odeku, 2012). This has the consequences of not only improving the living standard of the rural dwellers in Nigeria, as far as the social aspects, economic and education are concerned, but also reducing exposure to indoor smoke pollution, associated with fuelwood burning, which cause chronic health challenges. This would in turn reduce the mortality rate, in which Nigeria is among the highest in the world, and revamp the wellbeing of rural dwellers.

10. BENEFITS OF MICROGRIDS

Renewable energy in MG offers significant economic and political advantages such as the replacement of fossil fuel with permanently available home-grown energy; thereby enhancing energy security leading to a growth in the domestic production of goods and services in rural communities (Initiative GE, 2013). Adequately financed and operated MGs based on RE and appropriate resources can mitigate many of the challenges faced by traditional lighting or electrification strategies (Schnitzer et al., 2014). Some of the MGs implementation benefits are as follows:

i. Reliability: Due to availability of local generation and energy storage system (ESS), blackouts can be eliminated through the deployment of MGs (Kulkarni and Anil, 2014). Reliability is further improved in smart MGs.
ii. Integration of renewable sources: Due to variability characteristics of RE sources, integrating RE directly into the national grid is a challenge. However, the electrical boundary between the MG and the national grid makes it easier to integrate the RE sources for electricity generation.
iii. Demand response: MG is a technology seen as a sole entity to be controlled makes demand response easier to be adopted.
iv. Power quality: Electricity can be supplied at best voltage and frequency quality through deployment of DG, ESS, and an efficient Master controller,
v. Energy arbitrage: The MG can provide electricity back to the national grid or bilateral contracts at higher costs than the cost of generating the electrical energy (OECD, 2012).
vi. Cost savings: MGs provide significant cost savings through its defilement of grid extension. The cost of diesel fuel in operating generators is drastically minimised through the use of RE sources in MG (Iloeje, 2002)

In addition, MG offers rural communities new revenue sources; new job opportunities; capacity building and economic empowerment; innovation in products, practice and policies; and affordable energy (Pan Africa Solar, 2016).

There is a need for efficient MGs for cost effective electrification in rural communities. There are benefits of DG (through small hydro, wind, biomass and PV) and distributed ESS coupled with smart load management (through elastic loads). This will go a long way in mitigating the current energy crisis in Nigeria and other developing countries.

11. OPPORTUNITIES AND CHALLENGES OF MICROGRID

Renewable energy can create valuable job opportunities, especially when integrated into the local economic fabric. For example, the use of biomass (e.g., forest and crop residues, animal manure) as a renewable feedstock for the production of electricity, heating or biofuels is an untapped opportunity for rural development (Pan Africa Solar, 2016). MGs reduce dependency on conventional energy sources viz DG sets, etc., and preserve diesel/petrol as a result. A full-fledged MG provides functionalities like source prioritization, peak shaving, load prioritization and capacity management between generation resources, power export and import control, etc. Increased adoption of RE in the energy mix necessitates increased deployment of smart MG technologies.

Challenges of rural electrification include the high cost of grid extension to rural communities, lack of revenue in impoverished rural dwellers and the economic health of the national grid. The biggest challenges surrounding electricity supply in Nigeria include epileptic power supply if not total power outage in urban areas and lack of electricity supply to rural communities. Nigeria has been craving for all kinds of creative solutions and is enthusiastic to be adaptive and adoptive. Several new initiatives are being implemented in Nigeria by some different organizations.

A strong argument is being made for the possibility of successful rural community MGs. The challenges of introducing MG technology are not just technical but also socio-economic as rural dwellers will need to be trained to operate and maintain these systems. Rural MG models include solar-systems with batteries, wind/solar-DG hybrid systems, and full-fledged MG systems.

The challenges of MG are enumerated below:

i. Regulatory framework: Whilst there are the Independent Electricity Distribution Networks (IEDN), regulations and a draft regulation under consideration for Independent Electricity Transmission Network (IETN), there is still a considerable amount of uncertainty with respect to the regulations as it relates to off-grid projects. Hence, a lot of discretion remains with Nigeria Electricity Regulation Commission (NERC). Areas of uncertainty in the regulations include how to deal with excess power generated by either captive or off-grid generators, the issue of whether isolated urban IEDNs can exist within a DISCOs franchise area, applicability of the procurement rules to off-grid generators and applicability of the tariff methodology to off-grid generators, in view of the contradiction between the IEDN Regulations, 2012 and the NERC regulation for procurement of generation capacity, 2014.
ii. Requirement for licensing: This is an issue for captive power plants who only have permits to operate, and not license, when they have excess power generation. The captive power plants cannot sell power to willing buyers with their permits, but must obtain embedded generation license to sell power.
iii. Resistance or objections from existing monopolies: There is a likelihood of objections to the grant of off-grid licenses from DISCOs over the areas where their DISCO licences currently cover. NERC also maintains a balance to ensure that the DISCO's market share will not be eroded by the grant of an off-grid license.
iv. Access to gas: As mentioned earlier, where gas is the main fuel source, there may be issues with gas supply.
v. Technology gap: Nigerians need to develop the adequate technological know-how due to the fact that many of the off-grid equipment are sophisticated. It is common to find that many solar PVs installed pack up shortly after installation. Also, RE sources such as biomass and wind have not been fully explored in Nigeria, and would require adequate know-how for Nigerians to operate.
vi. Community orientation: This is a cultural issue in a lot of parts of Nigeria. It is more sort of self-centeredness and so trying to get a community to team up and organize to build a MG has been difficult.
vii. Other considerations: The start-up of off-grid MG power generation is usually capital intensive, and considerations include undertaking viable feasibility studies for the project; putting together the appropriate technical, financial and legal team for the project; adequate funding for the project;

ascertaining adequate costing for the project; obtaining clear title for the project land, identifying proposed off-takers for the project, and where applicable; available source of fuel and water amongst others. Another challenge is putting in place the right policy for MG deployment that will actually result in major improvements in electricity access rates.

12. RECOMMENDATIONS

The FGN says it has concluded plans to use RE to fast track its rural electrification projects across the country, using wind, solar, biomass and hydro-energy to complement the existing source of power supply. However, the following recommendations need to be adhered to:

i. It is required to create an investor friendly environment for MG off-grid solutions, with government support, tax incentives and reliefs to encourage investments in the rural electrification.
ii. Nigeria Government should intensify efforts in seeking funding support from the Developed Finance Institutions, World Bank and NGOs for the purpose of MG technology for rural electrification.
iii. For faster implementation of MG projects through the actualisation of long-term plans, the MG concept should be decentralised among the federal, state and local governments.
iv. There should be certainty in the regulations for MG technology and clarity with respect to the criteria for generally licensing the MG projects in urban and rural communities.
v. Avenue should be created by National Electric Regulatory Commission (NERC) to empower easier licensing for captive permit holders and MG licensees who have excess or stranded energy, and wish to sell to the DISCOs.
vi. NERC should device a workable compensation formula to form a win-win situation for investors and a DISCO, when such DISCO wishes to take over their franchise areas which was operated by an off-grid MG license. This way, the off-grid MG operator would be able to recuperate, at the minimum, the cost of its investment; and the DISCOs would in turn take over a crop of end users who have become used to paying their electricity bills. This will invariably encourage electric power developers to invest in areas within DISCOs' franchise areas (which are either poorly operated or not operated at all).
vii. Human capacity development is essential to accomplish adequate technological know-how for MG technology projects.
viii. A clear and sustainable strategy needs to be created by Rural Electrification Agency (REA) for funding and development of rural electrification. The projects would be appropriate for takeover by the power developers or even DISCOs where they are sustainable.

13. CONCLUSION

Power remains a main impediment to growth and development in Nigeria, as inadequate and unreliable electricity supply undermines economic growth, investment opportunity, social and infrastructure developments. Nigeria must diversify into the use of alternative sources to meet up with its energy needs as the country has some of the world's most abundant and least exploited RE sources, especially biomass, small hydro and solar power. These RE sources in MG can be used to generate the much-required electricity for the country's rural areas, rather than waiting in hopelessly for the national grid extension to these communities. Nigeria should join the on-going MG revolution as there is a developmental imperative for the country to also employ the Pay As You Go (PAYG) magic wand in solving the electricity crises by replicating the model in Nigeria. As on-grid MGs will help in strengthening the existing grid, the off-grid MGs will help supply the rural communities in most economical way thereby pave the way for private investors to participate in the electrification of the rural communities in Nigeria.

14. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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