Technical Economic and Environmental Analysis on the Potential of Solar and Wind Micro-Grid Systems in Nigeria

Omonigho P. Emenuvwe, Gbubemi K. Akporhonor, Happy Omokaro
University of Benin
Nigeria

Abstract

The exponential rise in electricity demand and erratic power supply in Nigeria accompanied by the depletion of mineral resources and the climate effects caused by the use of fossil fuels in the generating of power, calls out for the ever-increasing importance of the provision of alternate sources. To this end, this research study established an aim to carry out an analysis of the potential of Solar and Wind sources used in Microgrid Systems in Nigeria as a contributive solution to the power demand. While undergoing the research it was realized that Nigeria is endowed with lots of RES, solar, wind, hydro, et al spread across the various regions in the country. Locations were selected from both coastal and inland regions to cover both scopes of diverse climatic actions and analyses of the economic, technical, and environmental viability of these systems were carried out on Solar and Wind Microgrid systems. Solar Microgrid (MG) system happened to be the more economical power solution when it comes to the Levelized cost of energy (LCOE), however, the wind turbine MG generates more revenue with the shortest breakeven period based on the data used in this research. The two considered MG power solutions are environmentally friendly in comparison to the conventional power plants that use coal, diesel, and natural gas. Conclusively, both Microgrid systems are viable options in various parts of Nigeria and although more efficient in the inland regions can improve the amount of electricity generated and in turn mitigate the overall energy deficiency in Nigeria.

Keywords: Solar Energy; Wind Energy; Micro Grid systems; Renewable Energy Potential.

1. Introduction

The struggle for electrical power dates back to the late 19th century during the introduction of electricity to the world. Although electrical energy can be supplied in various ways, it needs to be made available to consumers with the highest form of quality, reliability, and lowest cost. The rapid and constant growth of energy demand worldwide has raised problems like supply difficulties and heavy environmental impacts (global warming, climate change, etc.). To better cope with the increased energy demand and reduce greenhouse gas emissions, a need to rethink and reevaluate the electric power system (PS) has arisen.

The microgrid system has been revealed throughout the world in recent years as one of the best solutions to provide reliable, less expensive, high-quality green electric energy [1]. Hence, it is considered a remarkable solution to the energy challenges because it creates a reliable supply of electrical energy to a power plant with the use of fuels that include the Renewable Energy System (RES). The proliferation of RES has made the concept of Micro Grid (MG) more reliable, resilient, and cost-effective along with several eco-friendly benefits as compared to conventional systems such as coal and gas-fired power system.

There are various renewable energy resources (such as small capacity hydro units, wind, solar, energy storage, et al) that can be considered for microgrid systems (MGS) for electrification both in urban and rural areas (especially where grid electricity access is not possible due to poor remote access and technical skills). MGS is emerging as an integral feature in shaping future power systems based on available smart grid initiatives. MGs are formed by integrating distributed generators (DG), energy storage devices (in some cases), and loads, like stand-alone systems, connected alongside grid electricity supply or as independent power generation and supply systems dependent on the consumer need, grid connection availability and utility connections.

The rise in the economy and population of the world brings about the rise in demand for more electrical power. This increase in demand comes alongside a corresponding decrease in supply. Hence, the increased consumption of more fossil fuels such as natural gas, oil, and coal as seen in Figure 1 is used in the generation of electricity to meet the excess demand [2].

A result of this is the pollution caused by the release of carbon and other harmful and unfriendly gases into the environment. Thus, it is expedient to proffer solutions to solve the current energy shortage and environmental pollution.

The aim of this research study is therefore to carry out an analytical study on Wind and Solar microgrid systems in relation to economic, technical, and environmental considerations. The study is significant as it brings about the viability of Solar and winds RES

MG systems as agents for carbon reduction in the power generation system in relation to environmental pollution in comparison to widely used fossil fuel and natural gas power plants with large carbon footprints. Besides the environmental considerations, it brings to grasp the economic impact of the MG system in relation to the benefits.

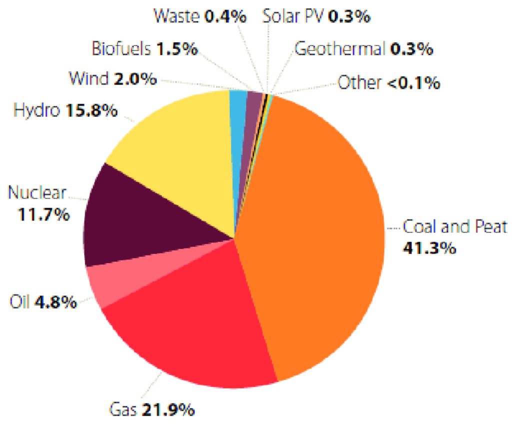

Figure 1. Percentage of fuel sources used in electricity generation

MGS may be expensive to install but the maintenance cost has proven to be low as developed technologies have reduced the price of systems associated with microgrids based on advanced technology. In developing countries such as Nigeria, the main grid power supply is not enough to meet the demand of consumers; hence, it will be of utmost significance if people can adopt the microgrid system architecture in bringing about stable, reliable, and cost-effective power solutions.

2. Literature Review

A microgrid system is a self-sufficient energy system that can either serve as a standalone system with regards to a discrete geographic footprint, such as a college campus, hospital complex, business centre, neighbourhood or connected to the main or utility grid just as any other power plant. It is local, which implies that its energy generated is to serve a certain locality as it provides a stable and reliable electricity supply, especially to locations where the main grid cannot reach. It is also cost-effective with regards to transmission and distribution as there is no necessary need for extended transmission and distribution supply lines to be built before they can reach certain remote locations[i]. RES microgrid systems can be independent which in this case implies they function as stand-alone systems when serving a particular location and is independent of the main grid. They are also considered intelligent due to their control system which helps to balance the generator's output, energy storage, and load.

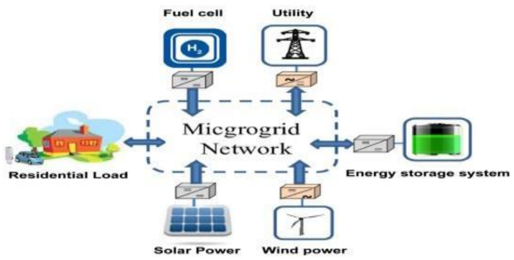

Figure 2. Microgrid System Network

From Figure 2, RES microsystems can serve in both capacity in supplying the right amount of power being consumed by loads within a location and still supply power to the utility grid. Hence, it serves both as the capacity of grid-tied and stand-alone or island grid systems. It uses energy generated from the sun (solar energy) which is captured and converted into electrical energy through the use of photovoltaic (PV) panels, stored in the battery if necessary, and distributed as clean energy [4] as seen in Figure 3.

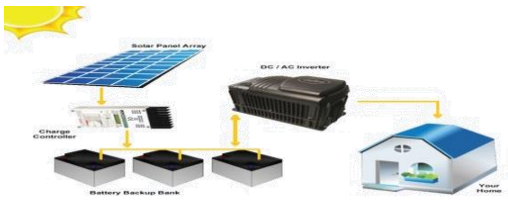

Figure 3. Solar microgrid system architecture

Solar microgrid systems are considered viable options for providing efficient, clean, and reliable power solutions which can be utilized remotely or placed on the main grid. Sets of arranged PV panels are used to capture solar energy that can be either stored in the battery or sent to the main grid after being converted using DC/AC inverter to the required power supply parameters.

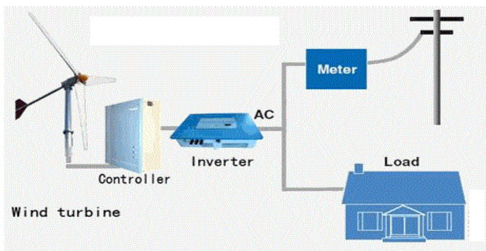

Figure 4. Wind Turbine Microgrid System architecture

Wind turbine microgrids function uses the same working principle as a solar microgrid. Wind turbines are used as a source of renewable energy [5] as seen in Figure 4.

Wind energy is converted into electrical energy and inverted into AC power supply in some cases aside from DC power supply being sent to either grid or used off-grid. Wind turbine microgrid is noisy and as such requires them to be installed in remote locations away from people and as such requires a high initial cost of power transportation.

3. Research Method

For this research study, secondary data were collected. The data obtained were centered on economic, technical, and environmental events that surround RES microgrid systems. The selected RES microgrids considered for this research were limited to solar and wind energy sources. The research conducted involved the use of secondary source data on different parameters reflected on the analytical factors of technical, economic, and environment. Hence, these factors became the framework to build the research methodology into begetting results. These factors have been developed to strategically evaluate the potential nature of an item, system, or business in terms of engagement, accessibility, and application. Hence, it helps in making decisions regards potential viability to be made concerning available options.

The essence of considering technical, economic, and environmental factors in analyzing an item or system is the fact that it can be adopted on a global scale as an acceptable process for effective analysis and evaluation.

3.1. Data Collection

3.1.1. Technical Data. Certain technical parameters enable the technology adoption and advancement in the use of the RES microgrid system. These parameters also function as drivers to determine the effectiveness, availability, and reliability of a power system. According to Table 1, the selected RES microgrid systems function with different energy sources.

The solar radiation and corresponding sunlight daily duration of five different locations within Nigeria were presented. The different locations were selected from both coastal and inland geographical regions, as highlighted in Table 2 [6]. Warri was considered for mangrove forest, Enugu for the tropical forest, Abuja for guinea savannah, Kano for Sudan savannah, and Maiduguri for Sahel savannah. It can be seen that Kano and Maiduguri locations have higher solar radiation and duration of sunlight than Warri and Enugu.

However, the installation of a solar microgrid system will still perform in producing electrical power in any location chosen except for the fact that the output power may vary since higher solar radiation and sunlight duration brings about higher electrical power.

The wind turbine microgrid system is required to function with a wind energy source. The wind has to be in motion to turn the blade of the wind turbine into producing electrical power. Hence, the wind has the velocity as presented in Table 3.

From Table 3, four locations were chosen in Nigeria, and data on their average wind speed throughout the year has been presented [6]. These locations were chosen from both coastal and inland regions within the country. On average, the wind speed ranges from 4m/s in the coastal regions (Port Harcourt) to 16m/s in the inland regions (Jos). Hence, inland regions such as Kano and Jos have higher wind speeds than coastal regions such as Port Harcourt and Lagos.

3.1.2. Economic Data RES microgrid systems have economic potential reflected in their ability to manage load demand with relatively energy exchange that is free. Estimating the economic viability of an item is concerned with the cost incurred on the acquisition of the item as against the benefits gained while utilizing the item. The research, therefore, considered some parameters on the economic factor of the selected RES microgrid systems for analysis and evaluation. One parameter of importance was the capital cost of the various RES microgrid power system as seen in Table 4.

The various cost obtained for the respective solar, and wind turbine microgrid was collated for a 1KW power system. Hence, a 1KW solar and 1KW wind turbine microgrid power system was considered for this research study.

By consideration, the electricity charge tariff from the main utility grid is \$0.059/kWh which customers currently pay in Nigeria on average. Also, in the case where electrical power generated from the microgrid can be sold, the tariff rate varies for the various RES microgrid systems. A solar microgrid system goes for \$0.06/kWh while wind turbine microgrid systems go for \$0.12/kWh [8].

3.2. Analysis of Data on RES Microgrid Systems

3.2.1. Technical Analysis. For the purpose of determining the average solar radiation and sunlight duration for each location, Equations 3.1 and 3.2 were used respectively.

$$Average\ solar\ radiation = Total\ solar\ radiation\ for\ the\ year \div 12 \quad \ldots\ldots\ldots\ldots\ldots\ (3.1)$$

Table 1. Technical Parameters on RES Microgrid Systems

Parameters	**Solar Microgrid**	**Wind Turbine Microgrid**
Energy Source	Sunlight	Wind
Operation Mode	Remote	Remote
	Grid-connected	Grid-connected
	Networked	Networked
Supply Voltage	DC	DC
Power Capacity (KW)	< 100	< 100
Life cycle period (year)	25	25
Energy Storage	Batteries	Batteries
Protection	Over voltage and current	Over speed, voltage and current
MTTF (h)	2910	1920
MTTR (h)	90	80

Table 2. Solar radiation and sunlight daily duration for Coastal and Inland regions

Location	Warri		Enugu		Abuja		Kano		Maiduguri	
Month	Solar Radiation ($MJ/m^2/day$)	Sunlight Daily Duration (h)	Solar Radiation ($MJ/m^2/day$)	Sunlight Daily Duration (h)	Solar Radiation ($MJ/m^2/day$)	Sunlight Daily Duration (h)	Solar Radiation ($MJ/m^2/day$)	Sunlight Daily Duration (h)	Solar Radiation($MJ/m^2/day$)	Sunlight Daily Duration (h)
Jan	19.61	5.4	19.9	6.3	20.8	8	20.3	8.5	20.32	9.2
Feb	19.9	5.5	20.4	6.4	21.6	8.3	22.6	8.8	22.9	9.4
Mar	18.58	4.9	20	5.9	21.7	7.4	23.7	8.2	24.5	8.9
Apr	17.59	5.4	19	6.1	20.7	7.2	23.6	8.3	24.64	8.5
May	16.26	5.3	17.7	6	19.3	7.3	22.6	9	23.71	9.1
Jun	14.14	4.2	15.9	5.1	17.7	6.6	21.6	9.2	22.82	8.9
Jul	12.54	3.2	14.2	3.7	16.1	5.2	19.4	7.8	20.54	7.5
Aug	12.84	2.9	13.8	3.6	15.1	4.8	18.2	7.5	19.2	7.1
Sep	13.23	3.3	14.7	4	16.4	6	19.9	8.4	20.66	8
Oct	14.64	4.5	16.5	5.6	18.3	7.9	21	9.2	21.22	9.8
Nov	16.88	6	18.5	7.4	20.4	9.3	21	9.4	20.56	10.1
Dec	18.7	6	19.4	7.3	20.6	9.2	19.8	9	19.29	9.6

Table 3. Wind speed for selected Coastal and Inland regions

Location	**Port Harcourt**	**Lagos**	**Jos**	**Kano**
Month	**Wind speed (m/s)**			
Jan	4.9	10.9	13.8	12.2
Feb	5.8	10.4	14.7	12.4
Mar	5.8	11.9	14.8	12.1
Apr	5.8	11.7	14	11.5
May	5.6	9.8	12.2	11.2
Jun	5.6	10.6	12.5	11.6
Jul	6.2	12	12.1	11.2
Aug	6.5	11.8	11.7	9.9
Sep	5.8	11.6	11.4	8.9
Oct	4.9	8.9	13.5	9.1
Nov	4.1	8.9	15.6	11.1
Dec	4.6	9.2	14.5	11.6

Table 4. Economic Parameters and Values

Parameters	Solar Microgrid	Wind Turbine Microgrid
Capital Cost ($/KW)	500	300
Installation cost ($/KW)	200	100
Interest rate (%)	10	6
Maintenance cost (per yr)	10	20
Inflation rate	17%	17%
Electricity tariff rate from main grid ($/kwh)	0.059	0.059
Tariff rate ($/kwh)	0.06	0.12
Replacement cost ($/KW)	700	400
Life cycle (yr)	25	25

$Average\ sunlight\ daily\ duration = Total\ sunlight\ daily\ duration\ for\ the\ year\ \div 12$ …………………………………………………………………………………..… ………………. (3.2)

3.3.Analysis of Data on RES Microgrid Systems

3.2.1. Technical Analysis. For the purpose of determining the average solar radiation and sunlight duration for each location, Equations 3.1 and 3.2 were used respectively.

$Average\ solar\ radiation = Total\ solar\ radiation\ for\ the\ year\ \div 12$ …………….. (3.1)

$Average\ sunlight\ daily\ duration = Total\ sunlight\ daily\ duration\ for\ the\ year\ \div 12$ …………………………………………………………………………………..… ………………. (3.2)

Hence, these calculated values were benchmarked against standard design parameters that make the power systems function effectively. Aside from functional consideration, these systems are subject to failure which requires maintenance but it is essential to note the frequency of failure and repair of the various power systems throughout their life cycle period as seen in Equations 3.3 and 3.4.

$Failure\ rate\ per\ year = (365\ \ 24) \div MTTF$ ………………………………………….. (3.3)

$Repair\ rate\ per\ year = (365\ \ 24) \div (failure\ rate\ \ MTTR)$ ……………………....... (3.4)

The 365 represents the number of days in a year and 24 represents the total hours in a day.

3.2.2. Economic Analysis. The total system cost comprises capital cost, installation cost, and interest rate as seen in Equation 3.5. Hence, the summation of these various costs brought about a total system cost

$Total\ System\ Cost = Capital\ Cost + Installation\ Cost + (Interest\ Rate\ \times Capital\ Cost)$ …………… (3.5)

However, if the system is subjected to tax benefit, it functions in favour of the power system and hence results in a net system cost as seen in Equation 3.6.

$Net\ System\ Cost = Total\ System\ Cost - Tax\ Benefit$ ………………………………… (3.6)

Throughout the useful life of the RES microgrid system, it produces power and cumulates over its useful life cycle as seen in the total production of Equation 3.7.

$$Total\ Production\ (KW) = \begin{pmatrix} Annual\ production - degraded \\ production\ due\ to \\ maintenance\ outage \end{pmatrix}\ life\ cycle$$ …………………… (3.7)

$Degraded\ Production = Production\ Capacity\ (KWh)\ \ MTTR$ ……………………… (3.8)

The Levelized cost of energy (LCOE) is obtained by dividing the net system cost by the total production (Simpleray, 2021) as seen in Equation 3.9.

$LCOE = Net\ System\ Cost + Total\ Maintenance\ Cost \div Total\ Production$ ……….. (3.9)

$$Total\ Maintenance\ Cost = Maintenance\ Cost \left(1 + \frac{inflation\ rate}{100}\right)^{life\ cycle}$$ … … … … … … … … .. (3.10)

The lower the LCOE value, the more economically viable is a product or system.

Another method of analyzing the economic viability of a microgrid system is to consider the revenue generated throughout its life cycle and compare it to the cost of electric power supply from the main utility grid.

The revenue generation associated with using an MG system can be obtained by multiplying the total production over a period by the selling tariff rate per unit of energy as seen in Equation 3.10.

$$Revenue\ Generation = Total\ Production\ \ Tariff\ Rate \qquad (3.11)$$

To calculate the breakeven of an MG power system, the revenue generated is compared with the total system cost plus the maintenance cost throughout its life cycle.

$$Total\ Life\ Cost(\$) = \left(Net\ System\ Cost + \left(10(1+0.17)^{25}\right)\right)$$

$$Total\ Life\ Cost = Net\ System\ Cost + Total\ Maintenance\ Cost \qquad (3.12)$$

$$Breakeven = \left(Net\ System\ Cost + (Maintenance\ Cost\ \ life\ cycle)\right) \div (Revenue\ Generation \div life\ cycle) \qquad (3.13)$$

Which involves the period with which the MG system can offset the cost of the project and start generating profit.

4. Result and Discussion

The analysis of RES microgrid systems is presented in this section. The selected microgrid system includes solar and wind turbine systems. Technical, economic, and environmental information was used to analyze these RES microgrid systems into highlighting their viability, reliability, and possible adoption for residential, commercial, and industrial buildings in Nigeria based on available data.

4.1. Technical Analysis

4.1.1. Solar MG System. Solar MG power system works with solar energy which gets converted to electrical energy through the use of solar panel modules. Hence, the source of energy is solar energy which is free and abundant but dependent on the location. Solar energy is presented in solar radiation which is rated in J/m^2. Figure 5, shows the average yearly solar radiation for five different locations in Nigeria.

The five locations considered were Warri, Enugu, Abuja, Kano, and Maiduguri and from Figure 5, it can be seen that Maiduguri has the highest yearly average solar radiation of 21.7MJ/m2day with a corresponding yearly average sunlight daily duration of 8.8hrs in a day. Maiduguri appears in the inland regions with the highest solar radiation and sunlight daily duration followed by Kano with 21.3MJ/m2/day and 8.6hrs and 19MJ/m2/day with a corresponding yearly average sunlight daily duration of 7.3hrs for Abuja.

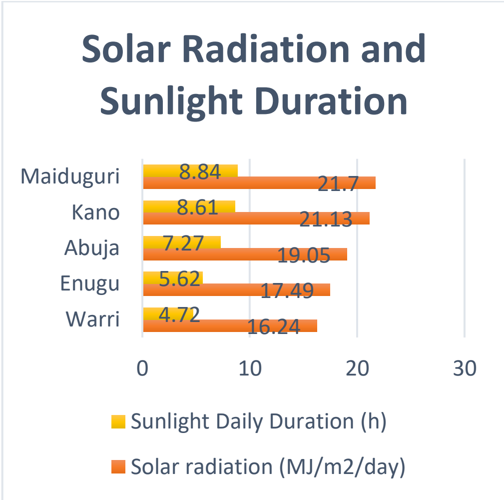

Figure 5. Yearly Average Solar Radiation and Sunlight Daily Duration

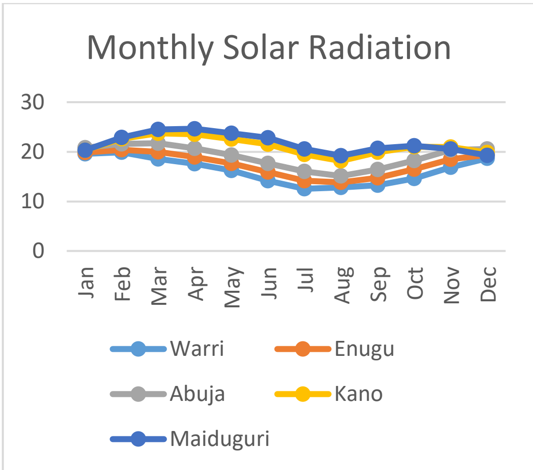

Figure 6. Monthly Solar Radiation of locations in Nigeria

While Enugu has an average yearly solar radiation of 17.5MJ/m2/day with a corresponding sunlight duration of 5.6hrs and Warri has an average yearly solar radiation of 16.24MJ/m2/day with a corresponding sunlight duration of 4.7hrs. To convert the solar radiation in MJ/m2/day to W/m2, the value was multiplied by 1000000 to convert MJ to J and divided by 86400s to bring the value to J/m2/s. By conversion, 1J/m2/s is equal to 1W/m2. Hence, on average solar radiation, Maiduguri is 251.2W/m2, Kano is 244.2W/m2, 219.9W/m2, Enugu is 202.5W/m2 and Warri is 187.5W/m2. Compared to ASTMG173 and ASDM E490 standards, the

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maximum operating solar radiation for any solar panel is 1000W/m2 at 25°C [9]. As long as there is little solar radiation, a solar panel module produces power output and as such, it has a direct link with the solar radiation [9].

Hence, an increase in solar radiation brings about an increase in the power output of a solar panel according to rated capacity.

The solar radiation curve from January to December appears similar for all five locations with the maximum solar radiation level occurring in March and April during the year, as seen in Figure 6. The lowest solar radiation for all five locations occurred during July and August. Although the solar radiation values for the locations in the inland region are higher than those from the coastal regions. The values were of proximity at the start month (January) and the end of the month (December) of the year as seen in Figure 6.

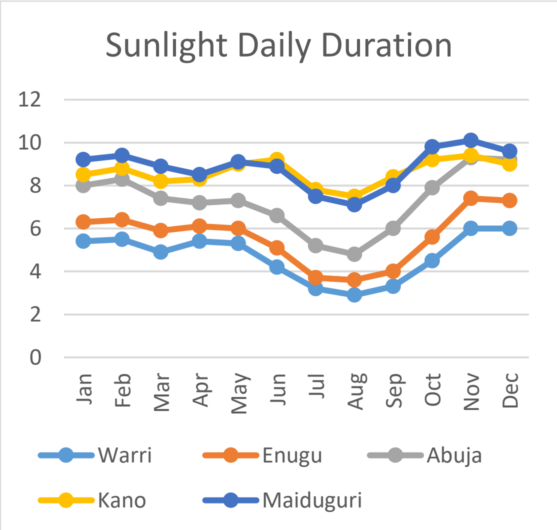

Figure 7. Monthly Sunlight Daily Duration for locations in Nigeria

According to Figure 6, the average sunlight daily duration is highest for Maiduguri, followed by Kano, Abuja, and Enugu before Warri throughout the year. The sunlight daily duration from January to December for the five locations follows the same curve pattern with the highest sunlight duration occurring around November and December while the lowest sunlight duration takes place around August. Using results obtained from Figures 6 and 7, it will be more appreciable to attain a higher electrical power output with the adoption of solar MG system more around locations within the inland regions. However, the use of solar MG power systems can still be adopted across all locations for both coastal and inland regions in generating as much power output through the use of more solar panels and battery storage systems.

For higher power output, mono crystalline and polycrystalline solar panels are used because of their life cycle of up to 25years and higher efficiencies. Although monocrystalline solar panel (24%) is more efficient than polycrystalline (21%) with the same panel surface area, the latter appears cheaper than the former but with a little price difference. So, therefore, it is recommended to use a mono crystalline solar panel when installing a solar MG power system.

The failure rate per year for solar MG power systems is as follows;

$$Failure\ rate\ per\ year = (365\ \ 24) \div 2910 = 3\ times$$

$$Repair\ rate\ per\ year = (365\ \ 24) \div (3\ \ 90) = 32.4$$

By calculation, the failure rate of a solar MG power system occurs 3 times and it takes about 32.4 actions to repair the system back to service over one year period. The lower the failure and higher the repair rates, the better the power system. This implies that at a lower failure rate, the system does not break down too often which may result in downtime, and at the same time, a higher repair rate is required to ensure that the system comes back in service within the shortest possible time.

4.1.2. Wind Turbine MG System. The wind turbine MG system functions with the use of wind speed as its driver to enable the rotation of the turbine blades which in turn rotates the shaft. The shaft is coupled to a DC motor (dynamo) using a gear system to vary the speed for the required output. The power output produced by a wind turbine can be rated as wind power density which is the number of wattages of electrical energy produced per square meter of air space (W/m²).

The recommended value for the installation of a wind turbine is normally given between 10m to 50m above the ground for effective functionality. By default, the available wind turbine MG generation capacity is determined using the average wind speed over a year for any location. Hence, locations that do not meet the wind speed requirement cannot be considered for the installation of a wind turbine MG system.

According to Betz's law, the maximum power output a wind turbine can generate does not exceed 59.3% of the wind kinetic energy, and as such, the wind speed curve has a strong correlation to the power generated [10]. Figure 8, shows values of wind speed throughout the year from January to December for four different locations (Port Harcourt, Lagos, Jos, and Kano). These four locations were considered to cover the regions of the country Nigeria. Port Harcourt and Lagos locations were considered in giving general information about the wind speed for the coastal regions while Jos and Kano were considered in providing information on the wind speed for the inland regions.

A wind turbine can be classified by its cut-in speed, rated (maximum production) speed, and cut-out speed. The operation wind speed classification for a wind turbine is attributed to the functions below.

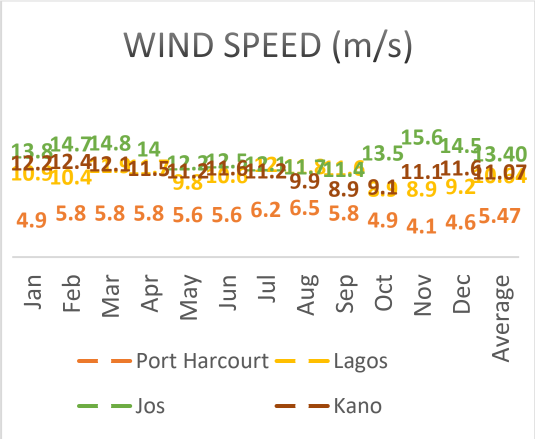

Figure 8. Monthly Wind Speed of locations in Nigeria

For large wind turbines, an increase in wind speed leads to a considerable increase in power output. Double wind speed for a wind turbine can produce as much as eight times its initial produced power output [11]. However, it has been discovered that a small wind turbine produces a more linear power output increase concerning the wind speed increase [5]. Hence, wind speed fluctuations result in wind electrical power generation capacity and the following characteristic are considered in determining the operation of a wind turbine [12].

- 2m/s is the minimum speed is required to start a rotating small wind turbine
- 3.5m/s is the cut-in speed for a small turbine to start generating power.
- 10-15m/s is for a wind turbine to generate maximum power.
- 25m/s is the cut-off speed or maximum speed for which a wind turbine is designed to break or stop.

According to Figure 8, the wind speeds for Port Harcourt appear to be the lowest when compared to Lagos within the same coastal region and also against Jos and Kano in the inland regions. The minimum speed for of wind speed for the Port Harcourt location was recorded to be 4.1m/s in November and a maximum of 6.5m/s in August with an average of 5.47m/s. By characterization, installing a wind turbine MG system will not be efficient as it cannot attain maximum power output since the required speed limit should be between 10 - 15m/s for that purpose. Although, the lowest speed of 4.1m/s enables the power system to cut in and start producing power output an installed wind turbine will keep performing at less than average capacity.

Hence, installing wind turbine MG in coastal regions with similar wind speed data such as Port Harcourt is not to be considered. The Lagos location coastal region presents different data in which the minimum wind speed is experienced at 8.9m/s during October and November while the maximum speed is seen at 12m/s in July with an average speed of 10.64m/s. By characterization, installing a wind turbine MG will be efficient in operation since its average wind speed falls between the required wind speed of 10-15m/s to generate at maximum capacity. Hence, it is recommended for wind turbine MG to be installed in any location within the coastal region with similar wind speed data.

For the inland region, the Kano location records an average of 11.07m/s which is about 2m/s less than that of Jos which is at 13.40m/s. The minimum wind speed based on Figure 8 for Kano and Jos locations are 8.9m/s and 11.7m/s occurring in September and August respectively. Also, the maximum wind speed for Kano and Jos locations are 12.4m/s and 15.6m/s occurring in February and November respectively. By characterization, both locations are suitable for the installation of wind turbine MG power systems in Nigeria as their average falls between 10-15m/s and will not experience any cut-off wind speed. It is worth noting that the wind speed data presented here for each month is an average of the various wind speed for different days during the month.

Hence, there is a possibility of some days where the wind speed may not be as high as the required wind speed for maximum capacity generation, and as such the expected power output will vary accordingly. However, this research will recommend the installation of a wind turbine MG power system in locations within the coastal region with similar wind speed information to those of Jos and Kano.

There are instances where the wind speed occurs at optimum which brings about maximum capacity being generated but not all power produced will be consumed. Hence, the load supply is higher than the load demand. To this end, the use of a battery to store an extra electrical charge for later use will bring about a more effective system. So, therefore, those periods with limited wind speed which corresponds to the low power output from the wind turbine will be compensated for using the energy stored in the battery especially when the load demand becomes greater than the supply.

The failure rate per year for solar MG power systems is as follows;

$$Failure\ rate\ per\ year = (365\ \ 24) \div 1920 = 4.6\ times$$

$$Repair\ rate\ per\ year = (365\ \ 24) \div (4.6\ \ 80) = 23.8\ times$$

By calculation, the failure rate of a wind turbine MG power system occurs 4.6 times within a year and it takes about 23.8 actions to repair the system back to service throughout one year. The lower the failure and higher the repair rates, the better the power system. This implies that at a lower failure rate, the system does not break down too often which may result in downtime, and also a higher repair rate is required to ensure that the system comes back in service within the shortest possible time.

4.2. Economic Analysis

Economic analysis is used as a tool to evaluate the cost incurred and associated effect of a RES microgrid power system throughout its useful life irrespective of the cost incurred during the disposal of the system. This work took to computing the total system cost for the three RES microgrid systems using Equation 3.5 and data obtained from Table 4.

$$Total\ System\ Cost\ (TSC_s) = 500 + 200 + (10\% \times 500) = 750$$

$$Total\ System\ Cost\ (TSC_w) = 300 + 100 + (6\% \times 300) = 430$$

The total system cost comprises the initial capital cost, and installation cost with the inclusion of an interest rate which happens to be 10% for solar and 6% for wind turbines. The total system cost for solar MG system was the highest when compared with wind turbine MG with the same capacity of 1KW. When this total system cost is considered alongside tax benefit, it brings about the net system cost which ought to be a reduced cost compared to the total system cost. However, such policy is not practised in Nigeria and as such, the total system cost is the same as the net system cost in US Dollars as seen below.

$$Net\ System\ Cost\ (NSC_s) = 750$$
$$Net\ System\ Cost\ (NSC_w) = 430$$

After establishing the net system cost for each system, it was important to compute the projected total production based on the 1kw capacity assigned to each MG system. It was assumed that each RES microgrid system, will generate power throughout the day as well as the whole year due to the incorporation of the battery system. This implies that the MG power systems will generate 1kw for 24hr throughout 365days in a year. However, due to failure which becomes ineviTable, the meantime to repair (MTTR) is taken into consideration as it reduces the total production output of the corresponding microgrid system for each year.

For a 1kw solar system using MTTR of 90h and a life cycle of 25 years,

$$Total\ Production\ (w) = \big((1 \times 365 \times 24) - (1 \times 90)\big) \times 25\big) = 216750$$

For a 1kw wind turbine system using MTTR of 80h and a life cycle of 25 years,

$$Total\ Production\ (w) = \big((1 \times 365 \times 24) - (1 \times 80)\big) \times 25\big) = 217000$$

Since the estimation of the RES microgrid is supposed to function effectively throughout a life cycle, 25years were employed for solar and wind turbine MG. By computation, the wind turbine MG system is designed to have the highest total production output compared to the solar MG system because it has a reduced MTTR value.

To determine the economic viability of each RES microgrid system, the LCOE value was computed.

$$LCOE_s = (750 + 506.57) \div 216750 = 0.0058$$
$$LCOE_w = (430 + 1013.15) \div 217000 = 0.0067$$

By definition, the lower the LCOE value, the more economically viable is a product or system. Working with the computed value above, the solar MG system appears to be the least viable power solution option when compared to the wind turbine microgrid system following the same generation capacity. Wind turbine MG is less viable when compared to solar which happens to be the best option based on having the lowest LCOE. The interpretation of this is that solar MG is a cheaper system since the investment cost of the system can produce more power (electricity) output compare to the other two microgrid systems. The solar system even had a higher net system cost than the wind turbine, the reverse was the case when it came to total maintenance cost and as such brought about a lower LCOE value.

Another method of analyzing the economic viability of an MG system is to consider the revenue generated throughout its life cycle and compare it to the supposed amount cost of electric power supply if the main utility grid was adopted as against the RES microgrid systems.

For solar,

$$Revenue\ Generation\ (\$) = 216750\ \ 0.06 = 13005$$

For wind

$$Revenue\ Generation\ (\$) = 217000\ \ 0.12 = 26040$$

The revenue generation associated with using an MG system can be obtained by multiplying the total production over the life cycle period by the selling tariff rate per unit of electricity. From all indications, the wind turbine MG system generates more revenue since it has the highest production output with a high tariff rate compared to the other considered RES microgrid systems. By comparison with the power supply from the main grid, the electricity tariff rates for the RES microsystems are higher than that of the main grid electricity tariff which happened to be \$0.059/kWh and as such will help users make a profit.

For investment purposes, the breakeven analysis of the various RES microgrid systems was considered. Breakeven is the time it takes for the power system to generate revenue and pay back the investment cost (capital expenditure and operation expenditure). By using equations 3.12 and 3.13, the breakeven was calculated to involve the total life cost of each system divided by the revenue generated in a year. But first, the total life cost was computed with an addition of the net system cost to the maintenance cost throughout the useful life of the system at a projection inflation rate of 17%.

Solar with a 17% inflation rate on the maintenance cost,

$$Total\ Life\ Cost(\$) = \left(750 + (10(1 + 0.17)^{25})\right) = 1256.58$$

$$Breakeven = 1256.58 \div (13005 \div 25) = 2.42$$

Wind with a 17% inflation rate on the maintenance cost,

$$Total\ Life\ Cost(\$) = \left(430 + (10(1 + 0.17)^{25})\right) = 1443.16$$

$$Breakeven = 1443.16 \div (26040 \div 25) = 1.38$$

By computation, it will take a wind turbine about 1 year and 5 months to breakeven followed by and solar microgrid system of about 2 years and 5 months. On average, the considered RES microgrid systems are estimated to break even within the first 2 years of operation and begin to make a profit throughout the rest of their life cycle period which is a minimum of 20 years. Hence, though the solar MG system may be the best when it comes to economic viability, it happens to be lower concerning revenue generation and breakeven period.

4.3. Environmental Analysis

Generally, RES microgrids are seen as environmental and climate-friendly because they enable the use of renewable energies [18]. MG power systems have demonstrated a focus on variable renewable energy integration, cogeneration, and energy efficiency [13]. All of these are considered reduction measures to emissions and as such holds potential for de-carbonization of the electricity system. For the large implementation of RES microgrid systems, battery storage such as lead-acid, lithium-ion, gel batteries, etc., gets employed to improve its all-around capacity generation. However, the use of these batteries has been studied to emit toxic substances and heavy metals into the atmosphere [ii]. Not to mention the fact that the recycling process is not entirely carbon-free as other forms of DG are used to bring about a recycled product [16]. So, therefore, the question asked here will be how green is solar and wind turbine microgrid systems?

The concept behind RES microgrid systems is that it functions without the direct emission of carbon and other toxic substances into the environment which results in pollution. However, there are activities associated with these MG systems that get to pollute the environment. Building and erecting wind turbines require materials such as steel, concrete, fibreglass, copper, and other toxic substances such as neodymium and dysprosium which are used as permanent magnets [17]. According to National Renewable Energy Laboratory, the biggest contribution to the carbon footprint of RES micro grids are steel, aluminum, fibreglass, carbon fibre, and epoxy resin to bind pieces together [17]. This is because the power required in producing these materials comes from coal, diesel, and natural gas generating plants around the world which are the main contributors to carbon emissions. Although, when this carbon footprint is amortized over the useful life span of RES microgrid systems which is a minimum of 20 years, it is seen that wind turbine microgrid is less than 99% carbon footprint when compared to coal-fired plants, less than 98% compared to natural gas-fired plants and less than 75% compared to solar microgrid systems.

The use of modern technology during the production of installation materials such as steel has emerged to reduce the carbon footprint caused by wind turbines, and solar MG systems. Instead of operating coal-fired plants to produce steel from iron ore as well as aluminum, green hydrogen electrolyzes which are powered through renewable energy source generators are now being used [19].

If this method is applied it can help reduce carbon footprint by some percentage depending on the quantity of material required in manufacturing solar panels or wind turbines. In furtherance of the reaction plan to reduce carbon footprints, development is currently ongoing to recycle old wind turbines, hydro turbines, and solar projects into new ones [16]. Hence, less energy is being consumed to recycle old systems into new ones compared to building a new system from scratch which will require a lot more energy consumption.

Aside from pollution resulting from carbon emission and solid waste, the aspect of noise pollution needs to be considered. For a fact, the solar MG system operates with no noise but this cannot be said for the wind turbine systems. The average noise level of a wind turbine placed at over 300m from houses is about 40db to 50db [20]. Also, the wind turbine MG is harmful to wildlife such as birds and possibly humans when in contact thereby leading to accidents.

In all of these, the RES microgrid system though may have some environmental drawbacks, is still a viable solution when it comes to the green power supply if the necessary precautions and control measures are observed.

5. Conclusion

Nigeria is endowed with RES in the form of solar, wind, and water, as highlighted in the research. Locations within Nigeria were chosen when analyzing the feasibility of adopting either solar or wind turbine. Based on secondary data obtained and analyzed, the inland region which includes locations such as Maiduguri and Kano displayed the potential of having solar MG systems adoption due to the presence of more solar radiation and sunlight daily duration on average throughout the year compared to coastal regions. Similarly, locations such as Jos and Kano experience higher wind speed compared to coastal locations and as such present a potential for the adoption of wind turbine MG systems. Although average wind speed across the country is sufficient to operate a wind turbine MG system the wind speed recorded for the coastal region locations is less than 10m/s on average and as such makes it difficult for a wind turbine system to attain maximum output capacity.

Based on the economic analysis carried out in the study, it was noted that the solar MG power system had the highest LCOE compared to a wind turbine. But in all, the two MG systems identified in this research are environmentally safe for the environment and become profitable after the first three years of operation because there is no operational cost and source-costs fuel is free, as compared to other conventional power plant systems which require fuel such as coal and natural gas to function. After due consideration, this research recommends that since there is a presence of solar radiation and acceptable wind speed across the country of Nigeria, people can take to adopting either a solar MG system or wind turbine MG system irrespective of the region. For locations with limited solar radiation, sunlight duration and wind speed can incorporate more panels and batteries into the system for storage for later use.

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