JEAS

JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

Journal of Engineering and Applied Sciences, Volume 20, Number 1, December 2022, 625 - 642

Microgrid sizing for rural electrification in Nigeria

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Abstract
The results obtained from electricity demand studies mostly point to the fact that the current gap between supply and demand in developing countries is already very substantial and that, it will become more entrenched under a 'business as usual' scenario. It's hard to run a business or a home without power, and those lucky few who are connected to a grid usually find electricity erratic and unpredictable. As a result, Africans self-generate a significant portion of their electricity with highly polluting off-grid alternatives and at a cost that is more than twice the cost of grid-based power. In Africa where most of the countries have extremely low electrification rates, microgrids have been set up to try and bring electricity to people living in villages. With distributed generation comes several issues like power quality assurance (from the several generating stations), balancing energy demand and supply, security, smart metering for tariff management, etc. In this paper, a microgrid sizing for rural electrification in developing countries is done. The methodology employed in this work involved the characterization of the test bed, sizing of the test bed, and data collection from the test bed to enable the efficient design of the microgrid. The procedures employed in this work showed that it helps to eliminate the problem of over sizing, energy wastage, reduce cost of the battery storage, improve batteries depth of discharge and energy charge cycle of the battery bank. This is because this research work employed real time field measurements of the testbed, and also captured the solar data readings unique to the region of usage.

Keywords: Microgrids, Smart grid, ELDI, Electrification, Smart City

1. Introduction

In the coming years, electricity demand is expected to rise significantly. Household electricity demand, which has the largest share, will rise due to growing urbanization (at a rate of 4.23% per annum) and population growth (estimated at 2.7% per annum, while global growth rate is 1.1%), at rates more than twice global averages. Industrial and commercial demand is also expected to increase as Nigeria slowly rise from the recent recession (with projected gross domestic product rates trending between 4.50% and 7%. A GIZ study estimates electricity demand to rise to 45,490 MW by 2020 and by 213,122 MW by 2040 (Cseaafrica, 2021).

Although the results of electricity demand studies vary widely, they all conclude that the current gap between supply and demand is already very substantial and that, it will become more entrenched under a 'business as usual' scenario. It's hard to run a business or a home without power, and those lucky few who are connected to a grid usually find electricity erratic and unpredictable. As a result, Nigerians self-generate a significant portion of their electricity with highly polluting off-grid alternatives and at a cost that is more than twice the cost of grid-based power. Millions of Nigerians buy their own generators—making this noisy scene now commonplace across the country.

In recent years, as the development of the modern technologies in information, communication, control and computing, our living environment is becoming "smart." Smart Home and Smart City have gradually become part of our lives, and are no longer merely future concepts for the public. An important component of Smart City is the Smart Grid (SG), which is regarded as the next generation power grid to create a widely distributed energy generation and delivery network. Smart grid technologies find application across the world. This ranges from isolated islands to very large integrated systems. In the developed world, smart grid technologies enable the upgrading and extension of existing grid systems, while providing opportunities for the incorporation of innovative solutions. In developing countries, smart grid technologies are essential to avoid lock-in of outdated energy infrastructure and attract new investment streams. This creates an efficient and flexible grid system that accommodates the rising electricity demand and a range of different power sources (Ezeagwu et al, 2018). Microgrid is a crucial and vital part of the development of smart grid. The microgrid is typified as the “building block of smart grid”. It consists of low voltage (LV) system with Distributed Energy Resources (DERs) collectively with storage devices and flexible loads.

In Africa where most of the countries have extremely low electrification rates, microgrids have been set up to try and bring electricity to people living in villages. These microgrids utilise both conventional fuels and renewable resources. The majority are based on Solar PV deployed in areas that are isolated from the main grid. Due to insufficiency of transmission line capacity to attend with the increasing demand, more concern is growing towards distributed generators and microgrids. With distributed generation comes several issues like power quality assurance (from the several generating stations), balancing energy demand and supply, security, smart metering for tariff management, etc.

The microgrid can be seen as the building block of smart grids. It comprises low voltage (LV) system with distributed energy resources (DERs) together with storage devices and flexible loads. The DERs such as micro-turbines such as, fuel cells, wind generator, photovoltaic (PV) and storage devices such as flywheels, energy capacitor and batteries are used in a microgrid (Ezeagwu et al, 2018). A microgrid is a self-sufficient energy system that serves a discrete geographic footprint, such as a college campus, hospital complex, business center, or neighborhood. Within microgrids are one or more kinds of distributed energy (solar panels, wind turbines, combined heat & power, generators) that produce its power. In addition, many newer microgrids contain energy storage, typically from batteries.

Microgrids have been and continue to be a major focus for many researchers in the areas of distributed generation, energy systems, sustainable power and remote area electrification. In this section, a review of such works is done. In microgrid design, it is important to note that microgrids can be AC or DC. In deciding whether to go for AC or DC microgrids, Lotfi et al. (2016) recommends to consider the ratio of dc loads. In (Zhu et al., 2015), the state of microgrids in China basing on the past, present and future was discussed. The design and operation of a remote microgrid was carried out in Mizani and Yazdani (2009), and the results obtained showed that for such remote microgrids, the use of optimal rating of energy storage units and renewable generators together with an optimal unit dispatch mechanism leads to significant reduction in the lifetime cost and emissions. Ezeagwu et al. (2018) presented a study on the smart grid challenges, technologies involved, and the integration of renewable sources. This explored the challenges and technologies used in integrating smart grid with renewable energy sources so as to achieve the demand side management. In Chen et al. (2012), a study was carried out on the optimal sizing of energy storage for microgrids. The design used the cost of energy storage option as the factor in deciding the type of storage to be used. A comprehensive study on costs of various storage technologies has been carried out and published by Lazard-Lazard (2016), Jane (2020). The shortfall with these works is that they did not take into consideration the daily variations of the load or increase in demand. The potential problem with this approach is that it can lead to system oversizing, and thus leading to higher cost of the system.

The principal objective of the present paper was to limit the frequency and power deviations by the application of the proposed controller which has five parameters to be determined through optimization techniques. In the paper by Regad et al. (2020) , a comprehensive literature review of the main hierarchical control algorithms for building microgrids was discussed and compared, by pointing out their most important strengths and weakness. In Bhattacharyya (2012) and Rojas-Zerpa et al. (2014), the users’ electric needs were categorised into user classes, electric appliances and usage habits. This categorisation includes appliances, power ratings, and time windows within which an appliance may be switched on and actual hours in a day that an appliance is on. The accuracy of work by Bhattacharyya (2012) and Rojas-Zerpa et al. (2014) was affected by inaccurate predictions of the current and anticipated appliance inventory, power ratings, and times of usage. The authors of Mandelli et al. (2016) and Kanteh et al. (2015) also analysed the load profiles in rural areas. The problem with their approach is that they did not provide any information as to how the load profiles were generated. In this work, proper consideration is done of vital components and parameters necessary to facilitate the modelling of a microgrid.

2.0 Material and methods

The methodology employed in this work involved the characterization of the test bed, sizing of the test bed, and data collection from the test bed to enable the efficient design of the microgrid. The testbed is located at Electronic Development Institute (ELDI), Km 80 Enugu-Onitsha Expressway Awka Capital Territory, Abba Junction, P.M.B, 5099, Awka. ELDI is a Research Institute under National Agency for Science and Engineering Infrastructure. Abba is one of the communities in the present-day Njikoka Local Government Area of Anambra State, Nigeria. Abba lies on the 60 11′ N latitude, 60 55′ E longitude of the old Enugu/Onitsha trunk ‘A’ road through the local government headquarters, Abagana. . The Google map location of the test bed is as shown in figure 1.

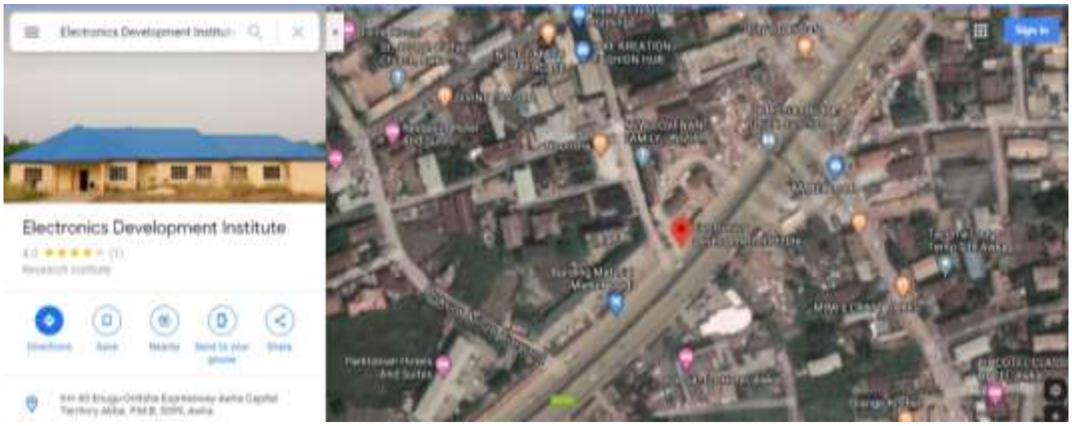

Figure 1 Google map location of ELDI

The microgrid developed by ELDI’s was aimed at integrating renewable energy sources (mainly solar) with both grid and DG facility. The solar array is as shown in figure 2.

Figure 2: Solar array

The system modeled in this work is a power distribution system in the microgrid environment with a certain number of sources, consisting of solar PV plants, storage batteries, generator set, and utility. The system contains an Energy Management System (EMS) that is responsible for coordination of all components of the microgrid. System sizing is a very critical step in the design of microgrids. This enables creation of load profiles that show the trend of electricity consumption as a function of time usually over a full day. Three main steps must be followed to calculate the proper size of a photovoltaic system.

a) **Estimate the required electrical energy (the demand)**

A load profile is developed by recording the power consumption of the equipment as well as the estimated usage time. Then the electrical energy required on a monthly basis is calculated. In doing this, consideration is made of the expected usage fluctuations due to variations between the rainy and dry season, school and vacation periods, etc.

The result will be 12 energy demand values, one for each month of the year. The power consumption also includes the inverter efficiency in the case of DC-AC conversion.

b) Determine the available solar energy (the resource)

Hourly Solar Resource Data is required to determine Solar PV production during 24-hours Load Cycle. Awka which is 6.210528 and the longitude is 7.072277. The study choice software used to obtain this data is the Hybrid Optimization of Multiple Electric Renewable (HOMER) software. HOMER is a performance and financial model designed to facilitate decision making for researchers Involved in Renewable Energy Industry. For the study, Weather Data File for Awka was obtained through its co-ordinates (Longitude and Latitude) using HOMER Platform. Hour-by-Hour Solar Resources was used to calculate solar PV power output consisting of hourly values of Solar resources for some time. Monthly Solar Resource Data were selected randomly to reduce errors due to climatic uncertainty of the year. Solar energy data is usually stated in monthly intervals, reducing the statistical data to 12 values. This estimation is a good compromise between precision and simplicity.

c) Combine energy demand and energy offer (the matching)

To determine that ratio the research divided the energy demand by the energy resource (peak sun hours). The month with the highest resulting figure is the month with the least favourable relation between energy demand and availability. The building is divided into three (3) blocks (containing different offices) with different load distribution. The load analysis of each block is conducted in this section. Since not all the load elements or appliances are rated in volt ampere, there is need to use equation (1) for power conversion. This is shown as (Jane, 2020):

$$P_w = 0.746\, P_{hp} \qquad (1)$$

Where, P_w is in kilowatt and P_{hp} is the power in horse power.
The efficiency in any system is expressed as

$$\eta = \frac{output}{input} x\ 100\% \text{ (Expressed in percentage)} \qquad (2)$$

This is written as (Jane, 2020):

$$\eta = \frac{P_o}{P_i} x\ 100\% \qquad (3)$$

Where P_o is the inverter output, P_i is the inverter input, η is the inverter efficiency. This implies that:

$$P_i = \frac{P_o}{\eta} \qquad (4)$$

Also, load analysis involves the summation of all appliances and equipment under consideration. Thus (Jane, 2020):

$$E_C = \sum E_i \qquad (5)$$

Where, E_C is the total energy of all appliances and E_i is the energy of each appliance. Also,

$$E_{cd} = E_c \div \eta \qquad (6)$$

Where, E_{cd} is the consumer energy demand taking inverter efficiency into consideration. In order to be more accurate, the energy consumption of the inverter while on standby will be taken into consideration, this make equation (6) to be modified as (Jane, 2020):

$$E_{cd} = E_c \div \eta + (P_{st} \times T) \qquad (7)$$

Where, P_{st} is the standby power consumption and T is the time the inverter stays on in a day. By using the various formulae stated in this section, the load analysis for the various blocks was done. The energy consumed by each block was calculated using equation (5). From the calculation, the following data was obtained.

TABLE I

TOTAL ENERGY AND POWER OF THE DIFFERENT BLOCKS AS MEASURED FROM THE TEST BED

BLOCK	TOTAL ENERGY (E_c)	TOTAL POWER (P_o)
Block A	1055192.28VAH	124556.38VA
Block B	264618.63VAH	39995.54 VA
Block C	287,776.69 VAH	39879.90 VA

The calculations for each block were done as follows:

1) Block A

The inverter to be used has the size which is calculated based on P_o. The system voltage is chosen to be 240V.

$$P_{inv} = 1.33P_o$$

$$P_{inv} = 1.33 \times 124556.38 = 165{,}650.99$$

$$P_{inv} \approx 1.66\ KVA$$

The battery sizing is necessary for off-grid solar PV infrastructure. Solar PV systems typically require deep cycle batteries. These batteries have an advantage of rapidly charging and discharging to a low energy level, making them highly efficient.

The system voltage is the dc voltage that the inverter is designed with and it usually becomes high as the power rating is becoming high. The battery discharge is given as (Jane, 2020):

$$D_B = \frac{E_{cd}}{V_s} \tag{8}$$

Where D_B is the battery discharge in (Ah), E_{cd} is the consumer energy demand in (VAh) and V_s is the system voltage in volts (V). D_B is the amount of charge that will be needed for the running of all the appliances. Another important factor to consider in the battery bank design, is the Depth of Discharge ($D_O D$). Draining the batteries completely is usually not advised as it decreases their lifespan. The Depth of Discharge (DOD) of the batteries is expected not to exceed 60% of the charge. This means that the battery can be discharged till 60% of its energy has been delivered. Maintaining this helps increase their lifespan. The percentage of battery capacity that will be used up per day by the load is given as (Jane, 2020):

$$C_B = \frac{D_B}{D_O D} \tag{9}$$

The $D_O D$ is very important and should by carefully choosing because it is not good to drain all the charges in the battery. For the battery design, recall that the E_c for block A was given as

$$E_c = 1055192.28\text{VAh}$$

$$E_{cd} = 1140622.25\text{VAh}$$

$$D_B\ \text{(battery discharge)} = \frac{E_{cd}}{V_s} = \frac{1140622.25}{240}$$

$$D_B = 4752.59\text{Ah}$$

For the battery capacity,

$$C_B = \frac{D_B \times D_A}{D_o D}$$

In this work, $D_o D$ was assumed to be 50% or 0.5 and days of autonomy be 3.

$$C_B = \frac{4752.59\ x\ 3}{0.5} = \frac{14257.77}{0.5} = 28515.56Ah$$

Calculations were also carried out to accurately determine the number of batteries that should be connected both in series and in parallel to form the battery bank. Assuming the unit battery capacity be represented by C_u and the number of battery to be connected in parallel in the battery bank is N_P, then the number of batteries to be connected up in parallel is given as (Jane, 2020):

$$N_P = \frac{C_B}{C_u} \tag{10}$$

To calculate the number of battery in series N_s, we use (Jane, 2020):

$$N_S = \frac{V_S}{V_u} \tag{11}$$

Where

V_s Is the system voltage

V_u Is the battery voltage

The total number of batteries that will be needed for the system was obtained using (Jane, 2020):

$$N_T = N_P \times N_S \tag{12}$$

Where N_T = is the total battery needed.

The unit battery specification that was used was given as 12V/200Ah. Thus $C_u = 200AH$

Thus the total number of battery in parallel in the battery bank that would serve the block is:

$$N_P = \frac{C_A}{C_u} = \frac{28515.56}{200} = 142.58 \approx 143$$

Also, the number of battery in series is given as:

$$N_s = \frac{Vs}{V_u} = \frac{240}{12} = 20$$

$$N_T = N_p \times N_s = 143 \times 20\ (140 \times 20) = 2860(2800)\ batteries$$

Having determined the total amount of batteries, the solar panel array design is considered. The design of solar panel array requires a practical value of peak sun hour.

The design is usually done based on the worst-case scenario. Table 2 shows the monthly averaged insolation incident on a horizontal surface in kwh/m2/day. The data was obtained using HOMER software.

TABLE III

MONTHLY AVERAGED INSOLATION INCIDENT ON A HORIZONTAL SURFACE IN KWH/M^2/DAY

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Insolation incident (kwh/m^2/day) 22 years average	5.64	6.02	6.24	6.29	6.08	5.50	4.92	4.71	5.1.19	5.66	5.78	5.73

The value of the sun hour that was used was that of the month with the lowest insolation. In this case it is 4.71 which is the August insolation.

$$h_s = 4.71$$

Due to the system losses, it is necessary to compensate it while deigning the PV array using the formula stated below. The photovoltaic array directly depends on the battery discharge therefore (Jane, 2020):

$$C_D = D_B + 0.2D_b = 1.2D_B \tag{13}$$

The 20% increment will account for all the possible losses in the PV array. C_D is the PV charge demand. Also,

$$I_P = \frac{C_D}{h_s} \tag{14}$$

Where,

h_s is the peak sun hour

I_P is the required PV current.

The peak sun hour is chosen from the established metrological data which depend on the location of the standalone system. The panel array peak voltage is obtained from:

$$V_P = V_{up} \times \frac{V_S}{V_{uu}} \tag{15}$$

Where,

V_S is the system voltage,

V_{up} is unit panel peak voltage,

V_{uu} is unit panel voltage,

V_P is panel array peak voltage.

The panel array peak power is obtained using the formula (Jane, 2020):

$$P_{pp} = V_P \times I_p \tag{16}$$

Where $P_{pp}$is panel array peak power.

To calculate the number of PV panels to be used, the formula used is:

$$N_{pr} = \frac{P_{pp}}{P_u} \tag{17}$$

Where P_u is peak power of panel and N_{pr} is the number of PV panels needed

The total number of panels to be connected in series and parallel is obtained as follows:

$$N_{ps} = \frac{V_S}{V_{uu}} \tag{18}$$

$$N_{pp} = \frac{N_{pv}}{N_{ps}} \tag{19}$$

Where N_{ps} is the number of panels in series and N_{pp} is the number of panels in parallel.

The PV charge demand is given as (Jane, 2020):

$$C_D = 1.2D_B$$

For Block A, $D_B = 4572.59Ah$, therefore

$$C_D = 1.2 \text{ x } 4752.59$$

$$C_D = 5703.11\text{Ah}$$

Also, the required PV current is obtained as:

$$I_p = \frac{C_D}{h_s} = \frac{5703.11}{4.71} = 1210.85A$$

Recall that the panel array peak voltage for block A was given as:

$$V_P = V_{up} \times \frac{VS}{V_{uu}}$$

The panel used has the following specifications

$$V_{up} = 35.5V = V_{oc}$$

$$P_{(wp)} = 280W_P$$

$$V_{uu} = 24v$$

Thus,

$$V_p = 35.5 \times \frac{240}{24} = 355V$$

The panel array peak power was obtained as:

$$P_{pp} = V_p \times I_P$$

$$= 355 \times 1210.85 = 429851.75W$$

The number of PV panels needed is obtained as:

$$\mathrm{N_{pr}} = \frac{\mathrm{P_{pp}}}{\mathrm{p_u}} = \frac{429851.75}{280} = 1535.18$$

$$\approx 1536 \text{ panels}$$

$$N_{ps} = \frac{V_s}{V_{uu}} = \frac{240}{24} = 10panels$$

$$N_{pp} = \frac{N_{pv}}{N_{ps}} = \frac{1536}{10} = 153.6 \approx 154 \; Pannels$$

Charge controllers helps to prevent the batteries connected to the panels from overcharging. In a microgrid, it is common to use more than one solar charge controllers. To determine the rating and amount of solar charge controller to be used, the following formulas are used. The rating of the charge controller is determined from (Jane, 2020):

$$I_{scc} = 1.2 I_P \tag{20}$$

Where I_P is the peak current from the panel array, and I_{scc} is the solar charge controller rating. The total number of charge controller required is determined from (Jane, 2020):

$$N_{scc} = \frac{1.2 I_p}{I_{su}} \tag{21}$$

Where N_{scc} is the total number of charge controller needed and I_{su} is the unit current rating of the charge controller needed.

Substituting (3.44) into (3.56), the following is obtained:

$$N_{scc} = \frac{1.2 C_D}{h_s I_{su}} \tag{22}$$

The total number of charge controller that was used was:

$$N_{scc} = \frac{1.2 C_D}{h_s I_{su}}$$

$$= \frac{1.2 \; x \; 5703.11}{4.71 \; x \; 100} \; (using\ charge\ controller\ 100A/240V)$$

$$\mathrm{N_{scc}} = 14.53 \approx 15$$

$$N_{scc} = \frac{1.2 \; x \; 5703.11}{4.71 \; x \; 50} \; (\text{Using charge controller 50A/48v})$$

$$N_{scc} = 29.06 \times 5$$

$$N_{scc} = 145.3 \approx 146 \text{ pieces}$$

It is also important to note that the size of the conductor to be used in the connections for this work plays a major role in the system losses. The resistance of the conductor decreases as the radius of the conductor increases. This is observed in the formula for resistance (R) in terms of resistivity (ρ), length (L), and radius (r) of the conductor.

From ohm's law, in any cable or resistive material

$$V = IR \tag{23}$$

Where V is the voltage drop, I is the current, and R is the resistance.

Also, the resistance of any conductive materials or cable is directly proportional to the length of the cable and inversely proportional to the cross sectional area of the cable. Mathematically, it can be stated as (Jane, 2020):

$$R\alpha \frac{L}{A} \; or \; R = \rho \frac{L}{A} \tag{24}$$

Where R is the resistance in ohm (Ω), L is the length of cable in meters (m) , A is the area of the cable in square-meter (m^2), and ρ is a constant of proportionality which depends on the material of the cable; it is called resistivity.

From equation (3.58)

$$R = \frac{V}{I} \tag{25}$$

Substituting equation (3.60) into (3.59), the following is obtained:

$$\frac{V}{I} = \rho \frac{L}{A} \tag{26}$$

Note that,

$$\rho = \frac{1}{\sigma} \quad or \; \sigma = \frac{1}{\rho} \tag{27}$$

Where σ is the conductivity of the material.

Substituting equation (27) into (26), the following is obtained:

$$\frac{V}{I} = \frac{1}{\sigma} \times \frac{L}{A} \rightarrow \; V\sigma A = IL \; \rightarrow \; A = \frac{IL}{\sigma V} \tag{28}$$

For an efficient connection, it is expected that the voltage drop across the two cables (positive and negative terminals) used for the connections should be a small fraction of the system voltage. This implies that (Jane, 2020):

$$V = KV_S \tag{29}$$

Where k is a constant set by the system designer.

Since there are two (2) cables of length L, thus the total length is $2L$. Substituting (29) and the total length of the cables into (28) gives:

$$A = \frac{2IL}{\sigma KV_S} \tag{30}$$

For the cable design, the allowable distance between the battery and solar panel should not be more than 10 meters for small capacity installation. The cable designed here is the main cable connecting the solar panels to the battery through the solar charge controller. The area of the conductor is obtained from:

$$A = \frac{2Il}{\sigma \Delta V}$$

Where I = I_p = 1210.85A

$l = 10$m,

$\sigma = 56$,

$\Delta V = 3\%\ of\ V_s$.

$$A = \frac{2\ x\ 1210.85\ x\ 10}{56\ x\ 0.03\ x\ 240} = \frac{24200}{403.2} = 60.06\ mm^2$$

ii. For Block B

The system voltage for block B was chosen to be 120V. The desired inverter rating was obtained as:

$$P_{inv} = 1.33 \times 39995.54 = 53194.07$$

$$P_{inv} \approx 54KVA$$

For the battery design, recall that the E_c for block B was given as:

$$E_c = 264618.63VAh$$

$$E_{cd} = 288144.86$$

$$D_B = \frac{E_{cd}}{V_s}$$

$$D_B = \frac{288144.86}{120} = 2401.21Ah$$

For the battery capacity,

$$C_B = \frac{D_B \times D_A}{D_o D}$$

Let D_0D = 0.5

$$D_A = 3\ (for\ three\ days)$$

$$C_B = \frac{2401.21\ x\ 3}{0.5} = 14407.24Ah$$

The unit battery specification that was used was given as 12V/200Ah. Thus $C_u = 200AH$

Thus the total number of battery in parallel in the battery bank that would serve the block is:

$$N_P = \frac{C_B}{C_u}$$

$$= \frac{14407.24}{200} = 72.03 \approx 72$$

Also, the number of battery in series is given as:

$$N_s = \frac{V_s}{V_u} = \frac{120}{12} = 10$$

$$\mathrm{N_s} = 10$$

$$\mathrm{N_T} = \mathrm{N_P} \times \mathrm{N_S} = 72 \times 10 = 720 \text{ Batteries}$$

$\mathrm{N_T}$ = Total number of batteries needed = 720 Batteries

Having determined the total amount of batteries, the solar panel array design is considered. The peak sun hour $\mathrm{h_s}$ is 4.7 as illustrated before.

$$\mathrm{C_D} = 1.2\mathrm{D_B}$$

$$\mathrm{C_D} = 1.2 \times 2401.21 = 288.45\mathrm{Ah}$$

Also, the required PV current is obtained as:

$$I_P = \frac{C_D}{h_s} = \frac{2881.45}{4.71}$$

$$\mathrm{I_p} = 611.77\mathrm{A}$$

The panel used has the following specifications

$$V_{up} = 35.5V = V_{oc}$$

$$P_{(wp)} = 280W_P$$

$$V_{uu} = 24v$$

Recall that the panel array peak voltage for block A was given as:

$$\mathrm{V_p} = \mathrm{V_{up}} \times \frac{\mathrm{V_s}}{\mathrm{V_{uu}}}$$

$$\mathrm{V_p} = 35.5 \times \frac{120}{24} = 177.5\mathrm{V}$$

$$\mathrm{P_{pp}} = \mathrm{V_p} \times \mathrm{I_p}\mathrm{P_{pp}} = 177.5 \times 611.77 = 108589.18\mathrm{W_p}$$

The number of PV panels needed is obtained as:

$$N_{pv} = \frac{P_{pp}}{P_u} = \frac{108589.18}{280} = 387.82$$

$$N_{ps} = \frac{V_s}{V_{uu}} = \frac{120}{24} = 5 panels$$

$$N_{pp} = \frac{N_{pv}}{N_{ps}} = \frac{38782}{5} = 77.56 \approx 78\, panels\ \mathrm{N_{pp}} = 78 \times 5 = 390$$

$\mathrm{N_{pp}}$ = 390 panels (total number of panels needed)

The total number of charge controller that was used was obtained from:

$$N_{scc} = \frac{1.2C_D}{h_s I_{su}}$$

$N_{scc} = \frac{1.2x2881.45}{4.71x50}$ (Using charge controller of 50A/24V)

N_{scc} = 14.68 ≈ 15 (parallel number of charge controllers)

N_{Tc} = 15 x 5 = 75 pieces. (N_{Tc} Is the total number of charge controller needed)

Taking the distance between the solar panel and the battery to be 10 meters, the cable used is copper and allowable drop of 3% along the cable. In calculation the cable size, the following values were used:

l=10m, $\sigma = 56$, I = $I_P = 611.77$A , V_s = 120V, and $\Delta V = 3\%\ of\ V_s$

The area of the conductor was obtained as:

$$A = \frac{2Il}{T\Delta V}$$

$$\Delta V = \frac{3}{100}\ x\ 120$$

$$\Delta V = 3.6V$$

$$A = \frac{2x611.77\ x\ 10}{56\ x\ 3.6} = \frac{12235.4}{201.6}$$

A = 60.69

A = 61mm^2

iii. For Block C

The inverter to be used was selected based on appliances' power requirements. The total power of all the appliances is P_o.

P_o = 39,879.9VA

$$P_{inv} = {}^{4}/_{3}\, P_o$$

$$P_{inv} = \frac{4\ x\ 39{,}879.9}{3}$$

$$P_{inv} = 53.173.2\text{VA}$$

$$P_{inv} = 54\text{KVA}$$

The system voltage was chosen to be 120V which is the DC input voltage of the inverter

For the battery design, recall that the E_c for block C was given as:

$$E_c = 287{,}776.69\text{Vah}$$

$$E_{cd} = 312{,}494.01\text{Vah}$$

$$D_B = \frac{E_{cd}}{V_s} = \frac{312\ 494.01}{120}$$

$$D_B = 2604.12\text{Ah}$$

For the battery capacity,

$$C_B = \frac{D_B\ x\ D_A}{D_o D}$$

Let D_0D be 0.5 and days of autonomy be 3Days, so that:

$$C_B = \frac{2604.12\ x\ 3}{0.5} = 15624.72Ah$$

The unit battery specification that was used was given as 12V/200Ah. Thus $C_u = 200AH$

Thus the total number of battery in parallel in the battery bank that would serve the block is:

$$N_p = \frac{C_B}{C_u}$$

$$N_p = \frac{1562.72}{200} = 78.12$$

Also, the number of battery in series is given as:

$$N_s = \frac{V_s}{Vu}$$

$$N_S = \frac{120}{12}$$

$$N_s = 10$$

$$N_T = N_P \times N_S$$

$$= 78.12 \text{ x } 10$$

$$N_T = 781.2$$

Approximately 790 pieces (total number of batteries needed)

Having determined the total amount of batteries, the solar panel array design is considered. Recall that from (3.43) that the PV charge demand is given as:

$$C_D = 1.2D_B$$

For Block C, D_B = 2604.12AH, therefore:

$$C_D = 1.2 \text{ x } 2604.12$$

$$C_D = 3124.94\text{Ah}$$

Also, the required PV current is obtained as:

$$I_p = \frac{C_D}{h_s}$$

$$I_p = \frac{3124.94}{4.71}$$

$$I_p = 633.47\text{A}$$

Recall that the panel array peak voltage for block A was given as:

$$V_P = V_{up} \times \frac{Vs}{V_{uu}}$$

The panel used has the following specifications:

$$V_{up} = 35.5V = V_{oc}$$

$$P_{(wp)} = 280W_P$$

$$V_{uu} = 24v$$

$$V_p = 35.55 \text{ x } \frac{120}{24}$$

$$V_P = 177.5\text{V}$$

The panel array peak power was obtained as:

$$\text{P}_{\text{pp}} = \text{V}_{\text{p}} \times \text{I}_{\text{p}}$$

$$\text{P}_{\text{pp}} = 633.47 \text{ x } 177.5$$

$$\text{P}_{\text{pp}} = 112440.93\text{W}$$

The number of PV panels needed is obtained as:

$$N_{pv} = \frac{P_{pp}}{P_u}$$

$$N_{pv} = \frac{112440.93}{280}$$

$$N_{pv} = 401.57$$

$$N_{ps} = \frac{V_s}{V_{uu}}$$

$$N_{ps} = \frac{120}{24} = 5 panels$$

$$N_{pp} = \frac{N_{pv}}{N_{ps}}$$

$$N_{pp} = \frac{401.57}{5}$$

N_{pp} = 80.31 ≈ 81 panels

N_{pp}= 81 x5 = 405 panels (total number panels needed)

The total number of charge controller that was used is:

$$N_{scc} = \frac{1.2_{CD}}{h_s I_{su}}$$

= $\frac{1.2 \ x \ 3124.94}{4.71 \ x \ 50}$ (based on 50A/24Vcharge controllers)

N_{scc} = 15.92 (parallel number of charge controllers).

N_{Tc} = 15.92 x 5 = 79.6

N_{Tc} ≈ 80 (total number of charge controller needed)

Again, we assume the distance between the solar panel array and the battery bank to be 10meters, using copper cable with 3% allowable voltage drop. The values are stated thus:

V_s = 120V, I_p = 633.47A, l=10m, $\sigma = 56$, and $\Delta V = 3\% \ of$ V_s

ΔV 0.03 x 120 = 3.6V

A = $\frac{2Il}{\sigma \Delta V}$

A = $\frac{2x633.47 \ x10}{56x3.6}$

A = 62.84mm^2

A = 63mm^2

Table 3 contains the summarized data calculated for the microgrid.

TABLE IIIII
DATA FOR ALL THE BLOCKS

Variable	Block A	Block B	Block C
Total appliance Energy $E_{c\ (Vah)}$	1055192.28	264618.63	28777
Consumer Energy Demand E_{cd}(Vah)	1140622.25	288144.86	31249
Total Appliances Power P_o (VA)	124556.38	39995.54	39879.
Inverter Power Rating P_{inv}(KVA)	166	54	54
Battery Discharge D_B (Ah)	4752.59	2401.21	2604.
Battery Capacity C_B (Ah)	28515.56	14407.24	1562
Battery needed N_T	2860	720	790
Total P_v current I_p (A)	1210.85	611.77	633.47
Panels Needed N_{TC}	1540	390	405
S_{cc} Needed N_{TC}	146	75	80
Cable size A(mm^2)	60	61	63

3.0 Results and Discussions

The results obtained in this section serve as a guide for designers, to ensure accurate sizing that makes for an affordable PV microgrid. Even though the testbed sizing had already been done by the original designers of the microgrid, it was important that another sizing was done in this work. This is because the author cannot account for the accuracy of the original sizing. It is important to note that poor load estimation leads to undersizing/oversizing of the system. This in turn leads to a less reliable system or one that is very costly. Accurate modelling enables us to create load profiles that show the trend of electricity consumption as a function of time. It helps to represent the quantity of energy in Watthours (Wh) that the particular users require in a given day. The procedures employed in this work, if adopted in the design of any microgrid in the region, it would help to eliminate the problem of over sizing, energy wastage, reduce cost of the battery storage, improve batteries depth of discharge and energy charge cycle of the battery bank. This is because this research work employed real time field measurements of the testbed, and also captured the solar data readings unique to the region of usage.

4.0. Conclusion

In time past, microgrids were only deployed in areas such as military bases, hospitals etc. where there was critical need for distributed generation. The increasing demand for energy, and the disruptive economic trends, coupled with a diversity of other reasons, microgrid development is fast proliferating. The use of distributed energy resources are becoming a cost-effective solution for many business and government organizations. Research has shown that the cost to build and operate distributed energy resources are rapidly decreasing. In Africa where most of the countries have extremely low electrification rates, microgrids have been set up to try and bring electricity to people living in villages. With distributed generation comes several issues like power quality assurance (from the several generating stations), balancing energy demand and supply, security, smart metering for tariff management, etc. In this paper, a microgrid sizing for rural electrification in developing countries was done.

5.0 Recommendation

COREN, NSE, SON and other relevant bodies like NAFDAC must ensure the quality of materials. Solar panels Inverters charge controllers must be subjected to extensive testing in other to ensure the quality and durability of the electronic items. Stamp and Seal should be developed for certified solar instructors.

Acknowledgements

The authors seek to acknowledge the staff and Management of the Faculty of Engineering, Nnamdi Azikiwe University, Awka. They all have been of great and immense help.

References

Cseaafrica. 2021. Challenges and Interventions Needs in the Nigerian Electricity Supply Industry (NESI). Available: http://cseaafrica.org/challenges-and-interventions-needs-in-the-nigerian-electricity-supply-industry-nesi/, visited:[September 1, 2021]

Ezeagwu C. O, Obioma Peace C, Ezelu Onyeka E, Obanor Patrick. 2018. Conceptual Study on Renewable Energy and Electric Vehicle Integration in Smart Grids. International *Journal of Advances in Scientific Research and Engineering (IJASRE)*. 4(4)

Lotfi, H. Member, S. Khodaei. A. 2016. Hybrid AC / DC Microgrid Planning. *IEEE Trans. Power System*. 8(1) :296–304.

Rojas-Zerpa, J.C. and Yusta, J.M., 2014. Methodologies, technologies and applications for electric supply planning in rural remote areas. *Energy for Sustainable Development*, *20*, pp.66-76.

Jane N. 2020. Design And Optimization Of A Renewable Energy Based Smart Microgrid For Rural Electrification. PhD Thesis Submitted To University Of Manchester.

Lazard, L. S 2016. Levelized Cost of Storage Analysis 2.0 Key Findings:10–12.

Regad M M. Helaimi, R. Taleb, Hossam A. Gabbar, Ahmed M. Othma. 2020. Semiconductor Defect Engineering: Materials. Synthetic Structures and Devices II.

Bhattacharyya, S.C., 2012. Review of alternative methodologies for analysing off-grid electricity supply. *Renewable and Sustainable Energy Reviews*, *16*(1), pp.677-694.

Kanteh S. S., Sani H. A., Wu, J., Saja S. E. and Ademi, S., 2015. Assessment of stand-alone residential solar photovoltaic application in sub-Saharan Africa: a case study of Gambia. *Journal of Renewable Energy*, *2015*.

Mandelli, S., Merlo, M. and Colombo, E., 2016. Novel procedure to formulate load profiles for off-grid rural areas. *Energy for Sustainable Development*, *31*, pp.130-142.

Mizani, S. and Yazdani, A., 2009, November. Design and operation of a remote microgrid. In *2009 35th Annual Conference of IEEE Industrial Electronics* (pp. 4299-4304). IEEE.

Chen, S.X., Gooi, H.B. and Wang, M., 2012. Sizing of energy storage for microgrids. *IEEE transactions on smart grid*, *3*(1), pp.142-151.

Zhu, X., Han, X.Q., Qin, W.P. and Wang, P., 2015. Past, today and future development of micro-grids in China. *Renewable and Sustainable Energy Reviews*, *42*, pp.1453-1463.