The Electricity Journal 33 (2020) 106765

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/tej

# Off-grid photovoltaic microgrid development for rural electrification in Nigeria

T.Y. Salihu[a], M.F. Akorede[b,*], A. Abdulkarim[c], A.I. Abdullateef[b]

[a] Shaybis Nigeria Ltd, Oloje Road, Ilorin, Kwara State, Nigeria
[b] Advanced Power and Green Energy Research Group, Department of Electrical & Electronics Engineering, University of Ilorin, Ilorin, Nigeria
[c] Department of Electrical Engineering, Ahmadu Bello University, Zaria, Nigeria

ARTICLE INFO

*Keywords:*
Microgrid
Photovoltaic system
Off-grid system
Electricity
Rural communities

ABSTRACT

Access to electricity at affordable cost is an essential ingredient for rapid and sustainable economic development, which directly contributes to economic growth and poverty reduction of a community. This article presents the design and execution procedure of the photovoltaic microgrid system carried out at Lajolo Community and its neighbouring communities in Nigeria. The primary aim of the project is to provide clean electric power to the people of the communities to increase their productive capacities and improve the quality of life in the remote area. The work is equally intended to stimulate rapid economic growth, thereby generating new income alternatives that result in social well-being of the case study communities. The project, when commissioned in January 2018, has greatly improved the economic activities and social life of the beneficiary communities. It also increases the security of the communities at night. With the provision of a motorized borehole for irrigation system, the villagers, who are predominantly farmers, can now farm all year round with bumper harvest. In this paper, recent developments in the solar energy microgrid across the globe is also presented.

## 1. Introduction

Global energy demand has increased along with the world population and the need for a higher penetration of renewable energy has also increased. Recent predictions by the International Energy Agency (IEA) have shown that the demand for energy will triple by 2050 (Council, 2013). Presently, renewable energy sources contribute to less than 20 % of the world's energy (Zervos, 2015). Future predictions in Fig. 1 have shown that the percentage of the installed capacity of non-fossil energy systems will increase to 45 % by 2035. Also, the World Bank and the IEA have indicated the need to double the global installed energy capacity. This will help to meet the demand from the developing countries in the next 40 years.

Many countries are aiming for a higher penetration of renewable energy by 2050 as a result of this; the global share would be between 15 and 82 % as shown in Fig. 1. Denmark generates 39.1 % of its overall electricity from cleaner sources and has a target of 50 % and 100 % by 2020 and 2050 respectively. The United Kingdom aims to meet 15 % of the demand by 2020, when the Scottish and Northern Ireland governments intend to achieve 100 % and 40 % of renewable energy penetration respectively. The Welsh government indicates the potential of generating twice the amount of electricity it currently uses from renewable energy sources by 2025. In 2014, Germany generated 26 % of the country`s energy from renewable energy sources. Greece presently generates 10 % of its total energy from renewable sources and Spain has set a target of 40 % penetration of renewable energy by 2020. Ireland has one of the best wind resources, and has set a target of a 40 % penetration of renewable energy resources by 2020. China is the global leader in renewable energy in all senses, envisaging that 15 % of its energy needs will be from renewable energy sources by 2050. More renewable energy development in Asian countries can be found in (Webb, 2014) and in Africa in (Miketa et al., 2015).

Access to electricity at affordable cost is very essential to achieve a rapid and sustainable economic development. It directly contributes to economic growth and poverty reduction through wealth creation, especially in the rural areas. Undoubtedly, no community or country can develop and sustain beyond subsistence means without having at least minimum access to energy services for the larger portion of its population (Oseni, 2012).

According to the recent World Bank data conducted in 2014 (World Bank, 2017), about 46 % of Nigerian population has no access to the grid-connected electricity, despite that the country is endowed with

* Corresponding author.
*E-mail addresses:* tysalihu@ieee.org (T.Y. Salihu), akorede@unilorin.edu.ng (M.F. Akorede), abdulkarima@abu.edu.ng (A. Abdulkarim), abd_lateef.aii@unilorin.edu.ng (A.I. Abdullateef).

https://doi.org/10.1016/j.tej.2020.106765

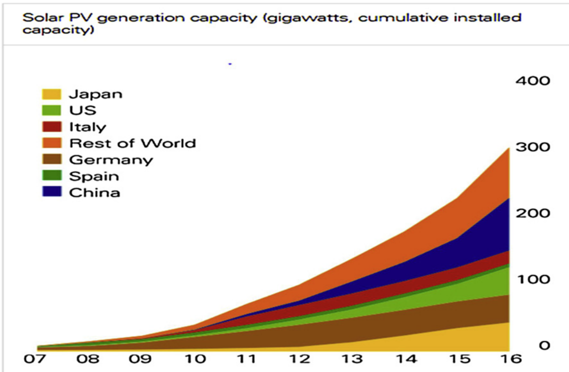


**Fig. 1.** Global installation of solar PV system (Abdulkarim et al., 2018).

abundant energy resources – fossil fuels and renewable energy resources. This large proportion of the population, especially in the remote areas still depend largely on the conventional forms of energy such firewood, kerosene, etc, for energy sources. Since Nigeria is abundantly endowed with renewable energy resources, they could be significantly developed to generate modern and clean electricity to meet the yearning demand of her citizens and yet conserve the environment from greenhouse gasses usually generated by the fossil fuel-fired power plants.

The primary aim of this microgrid project is, therefore, to provide clean electric power to the people in a remote area (Lajolo community and environs) in order to increase their productive capacities and improve their quality of life. The intent of the work is to stimulate rapid economic growth, thereby generating new income alternatives that result in social well-being of the case study communities. The choice of the communities is borne out of the interaction with the Kwara State Ministry of Energy that disclosed that the communities are not among those earmarked for provision of electricity by the State government in ten years' time. The other factor considered in favour of the communities includes difficulty in getting access to the communities due to poor or non-existent road leading to the communities.

A microgrid could be defined as a low voltage discrete energy system comprising distributed energy resources such as wind energy conversion system, solar photovoltaic system, fuel cells, etc, together with storage devices, which include flywheels, lead acid batteries, energy capacitors, etc, and flexible loads (Akorede et al., 2010; Hatziargyriou, 2014). Such system could be operated in a non-autonomous mode when interconnected with the main grid, called grid-connected system, or run in an autonomous mode when disconnected from the grid, otherwise known as island mode (Kim et al., 2019). However, the system requirements could be different in some aspects such as reliability, control and stability (Abdulkarim et al., 2018).

This pilot project is jointly funded by Shaybis Nigeria Ltd (SNL) – a private company based in Nigeria – and IEEE Smart Village (IEEE SV). The execution of the project was carried out in collaboration with the Advanced Power and Green Energy Research group of the Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria. The funding for the integrated irrigation system, to enable the farmers carry out farming activities all year round, was provided by Harmony Holdings Ltd, the investment arm of Kwara State government. The Holdings also arranged for provision of micro loans to the farmers to enable them to start farming immediately.

## 2. Solar energy microgrid developments across the globe

In this section, recent developments in the area of solar energy microgrid across the globe are presented. Recent survey shows that China is the leader in term of cumulative installation of solar energy with about one quarter of the world total solar energy installation. This is followed by Japan with installation of (42.8 GW) which is followed by Germany having (41.3 GW) and USA has cumulative installation of 40.3 GW making it the fourth in the world ranking. Future expectation is that the top four countries will add at least 20 GW by 2020. According to yearly ranking 2016 has witness the highest solar energy installation of about 26.6 % increased. Critical evaluation of the figure shows that the major installations of solar energy systems are China and Europe. It is unfortunate to note Tropical regions that are having higher potential of solar energy systems are left behind the schemes.

In terms of investments, Asia continent is dominating solar energy across globe. Also this development is as a result of many factors such as cost of solar panels, tax credits, financial facilitation, metering, and government policies. Due to these developments there many microgrid existing globally. Example of existing microgrid projects are presented in Table 1.

## 3. Solar energy potential in Nigeria

Nigeria is one of the countries in the world that are richly endowed with solar energy. According to a study (Akorede et al., 2017), the country experiences an annual average daily sunshine of 6.5 h, ranging from 4 h at the coastal areas to 9 h at the far northern boundary. This is equivalent to an average solar radiation of 3.5 kWh/m$^2$ and 7 kW h/m$^2$ in the two regions respectively. This radiation figure is quite significant but unfortunately Nigeria has not really fully explored this enormous resource, like several other countries in the world. With her vast land mass, Nigeria could generate several GWh of electricity annually when the solar energy potential is fully explored.

## 4. Rural electricity case study project

### 4.1. Brief description of the study area

Lajolo Community is located in Marafa/Pepele Ward in Ilorin East Local Government Area of Kwara State, Nigeria. The village comprises

**Table 1**
Samples of Microgrid Projects and Locations.

| Location | Type of sources | Source |
|---|---|---|
| USA | PV and diesel generator microgrid | (Kroposki et al., 2008) |
| Netherland, Holiday Park microgird | PV, diesel generator and storage, the system has peak generating capacity of 315 kW | (Kroposki et al., 2008) |
| Steinweg microgird, Germany | PV, diesel generator and storage of 880 Ah capacity | (Krishnamurthy et al., 2008) |
| Ricerca, DER microgrid, Italy` | PV, Diesel generator,, solar thermal, biomass, microturbine and battery storage | (Lidula and Rajapakse, 2011) |
| Kythnos island, Greece microgrid | PV, Diesel generator and battery storage | (Lidula and Rajapakse, 2011) |
| Nationa Techical university microgrid located in Greece | PV, wind turbine and battery storage | (Mitra et al., 2008) |
| Japan Aichi city airport microgrid | Fuel cell, PV and storage microgrid | (Barnes et al., 2005) |
| Kyotango, Japan eco-energy microgrid project | Gas turbine, fuel cells, PV and wind turbine | (Araki et al., 2009) |
| Akagi, research institute microgrid, Japan | PV and Storage | (Kroposki et al., 2008) |
| Sendai microgrid Japan | Gas turbine, fuel cells, PV and battery storage | (Hatta and Kobayashi, 2007) |
| Hefei University of technology, China | PV, wind turbine generator, fuel cell, battery bank, and small hydro | (Morozumi et al., 2008) |
| KERI, Korea | PV, wind turbine, diesel generator and battery | (Keeyoung et al., 2009) |


**Fig. 2.** Google map showing the location of the case study.

Lajolo and over 15 hamlets/quarters such as Dalemo, Jabi, Idiagbon, Suru, Pongu, Kendiri, Egede, Kanolu, etc. Lajolo alone has 29 households with estimated population of 2000 people. It is located on the latitude 8.66326173 N and longitude 4.94450628 E as illustrated in Fig. 2. The predominant occupation of the communities is farming, engaged by both men and women. In addition, there are a few women engaged in petty trading.

### 4.2. Electrical load survey of the communities

To estimate the load demand of the communities, a form was designed to collate data from members of the villages. Prior to that exercise, our team had held series of meetings with the communities involved to create awareness about the project and seek their utmost cooperation on the job, especially on the security of equipment to be installed. The team went from household to household to review the current economic conditions of the residence and the average monthly expenses incurred to operate and maintain generators by a few users. Other useful information collected from the communities includes the type and number of electrical appliances they are likely to use when electricity is finally supplied to them. This information was gathered to determine the load estimates shown in Table 2, even as some spare capacity is provided to cater for future demand due to expansion.

### 4.3. Sizing the solar energy system

Having estimated the amount of daily energy required by the communities from the previous section, the next step is to determine the sizing of the various components of the PV system. Since the proposed energy system will be a stand-alone one, the major components required are PV Modules, charge controller, inverter, and battery energy storage system, among other small but equally important components as shown in Fig. 3. Not minding the high cost, monocrystalline solar panel technology was selected for the project because of its high module conversion efficiency in warm weather such as one in Nigeria when compared with other solar cell technologies. Monocrystalline panels are also space-efficient in addition to long lifespan, as they yield the highest power outputs (Sendy, 2017).

Specifically, the solar panel of dimension 1644 × 986 × 35 mm selected for the project has +5% power tolerance and open-circuit voltage ($V_{OC}$ of 44.89 V. Its maximum system voltage is 1000 V while it has a peak power $P_{max}$) of 300 W. The short-circuit current ($I_{SC}$) of the module is 8.72 A.

#### 4.3.1. Inverter sizing and system voltage

With all 54.64 kW h/day running on a 92 % efficient inverter, the dc load that the batteries must supply would be:

$$dc\ Bat\ Load = \frac{ac\ Load}{Inv\ Efficiency} = \frac{54.64\,kWh/day}{0.92} = 59.4\,kWh/day$$

One guideline that can be used to pick the system voltage is based on keeping the maximum steady-state current drawn below around 100 A so that the readily available electrical hardware and wire sizes can be used. Using this guideline of the system voltage suggestions given in Table 3 (Sandia National Laboratories, 1995), our system voltage of 48 V was chosen.

With a 48-V system voltage, the batteries will be required to supply the following daily load demand:

$$ac\ Load = \frac{dc\ Load}{System\ Voltage} = \frac{59.4\,kWh/day}{48\,V} = 1,\,237.5\,Ah/day$$

The maximum ac power that the inverter should deliver was estimated by adding the power demand of all of the loads that will ever be anticipated to be operating simultaneously. From Table 1, the total ac power demand with everything turned on at once would be 7180 W, which would draw 143.3 A with the system voltage of 48 V. Therefore

**Table 2**
Estimated daily energy demand from survey.

| S/No | Appliance | No. of Device | Watts/Unit | Watts | Day (hrs) | kWh (Day) | Night (hrs) | kWh (Night) | Total kWh/day |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Mobile phone | 20 | 5 | 100 | 12 | 1.2 | 12 | 1.2 | 2.4 |
| 2 | Customer Light | 100 | 16 | 1600 | 0 | 0 | 12 | 19.2 | 19.2 |
| 3 | Water pump | 1 | 1000 | 1000 | 4 | 4 | 0 | 0 | 4 |
| 4 | Fans | 10 | 100 | 1000 | 2 | 2 | 4 | 4 | 6 |
| 5 | Television set | 5 | 200 | 1000 | 2 | 2 | 2 | 2 | 4 |
| 6 | Street Light | 5 | 40 | 200 | 0 | 0 | 6 | 1.2 | 1.2 |
| 7 | School Light | 4 | 20 | 80 | 1 | 0.08 | 2 | 0.16 | 0.24 |
| 8 | Freezer | 3 | 400 | 1200 | 8 | 9.6 | 0 | 0 | 9.6 |
| 9 | Future Enterprises | 5 | 200 | 1000 | 8 | 8 | 0 | 0 | 4.2 |
| | **Total** | | | 7180 | | **26.88** | | **27.76** | **54.64** |

an inverter with 8.5 kW capacity which is close to the 7.2 kW of the total required power was chosen for the project. The inverter operates at 230 Vac and 50 Hz frequency.

To calculate the usable storage capacity of the batteries, the following expression is used:

Usable storage = 1,237.5 Ah/day × 4 day = 4,950 Ah

**Table 3**
Suggested system voltages based on limiting current to 100 A.

| Max. ac Power (kW) | System dc Voltage (V) |
|---|---|
| < 1.2 | 12 |
| 1.2–2.4 | 24 |
| 2.4–4.8 | 48 |

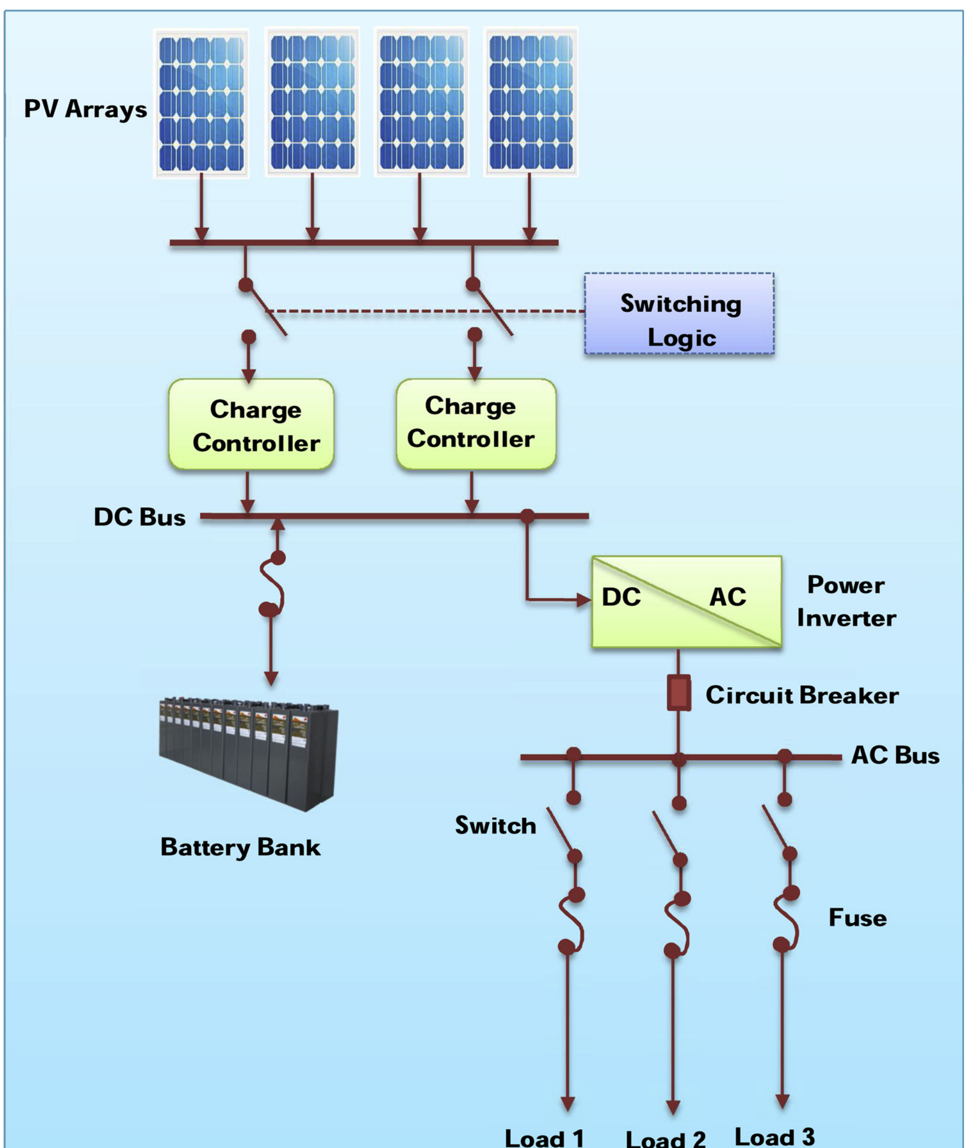


**Fig. 3.** The proposed Microgrid Topology for the Villages.

Four (4) days was chosen for the battery storage to be provided based on the information obtained from the guidebook published by Sandia National Laboratories on battery storage needed for a stand-alone system with 95 % system availability. This was regarded as the peak sun hours for the worst month of the year whereas availability is on an annual basis.

Deep-cycle batteries intended for photovoltaic systems are often specified in terms of their 20-h discharge rate ($C/20$), which is more or less of a standard. The total storage capacity of the battery bank, TSC, with a temperature of 25 °C is calculated as:

$$TSC = \frac{Usable\ storage\ capacity\ (Ah)}{MDOD} = \frac{4,950\,Ah}{50} = 9,898.60\,Ah/day$$

where MDOD is maximum depth of discharge.

The most important specification for an inverter is the amount of ac power that it supplies on a continuous basis. However, it is also critically important that the inverter be able to supply surges of current that occur when electric motors are started. Bearing these factors in mind, a 48-V inverter, which would allow plenty of future demand growth without exceeding the 100-A guideline, was therefore chosen for this system. The product of the rated current $I_R$ and peak hours of insolation provides a good starting-point to estimate the Ah delivered to the batteries. However, the common practice is to apply a de-rating factor of about 10 % to account for dirt and gradual aging of the modules as well as the battery efficiency measured as the Coulomb efficiency. We therefore have the expression:

$$Ah\ to\ Inverter = \mathrm{I_R} \times \text{peak sun hours} \times \text{Coulomb efficiency} \times \text{de-rating factor}$$
$$= 8.18 \times 4 \times 0.9 \times 0.9 = 26.5\ \text{Ah/day per string}$$

From the manufacturer's data sheet, the 300-W module has a maximum power point current of 8.18 A and a voltage of 36.68 V. For a 92 % efficient inverter to deliver 54.64 kW h/day of 230 V ac, it needs a 48-V dc input of

$$Inv\ dc\ Input = \frac{ac\ Load}{Inv\ eff \times System\ voltage} = \frac{54.64\,kWh/day}{0.92 \times 48\,V} = 1,237.32\,Ah/day$$

#### 4.3.2. Sizing the PV array

Since the modules have a rated voltage of 44.89 V, they are nominally "24-V modules." Therefore two modules are needed in series to provide a single 48-V string. The number of parallel strings of modules needed (Masters, 2013) is:

$$No\ of\ Parallel\ Strings = \frac{1,237.32\,Ah/day}{26.5\,Ah/day\ per\ String} = 46.7\,Strings$$

Suppose that we undersize it slightly and use 40 parallel strings with two modules per string, for a total of 80 modules. Including the 0.90 derating factor, the PVs will deliver:

$$PV\ output = 40\,strings \times 8.18\,A/string \times 4\,h/day \times 0.90 = 1,177.92\,Ah/day\ @\ 48\,V\ dc$$

The batteries with 0.90 C efficiency will deliver:

Battery output = 1,177.92 Ah/day × 0.90 = 1,060.13 Ah/day @ 48 Vdc.

Therefore, a battery of 1202 Ah was chosen. With 92 % efficiency, the inverter will deliver:

Inverter output = 1202 Ah/day × 48 V × 0.92 = 53.08 kW h/day @ 230 Vac

So, the design is slightly less than the desired amount of 54.64 kW h/day, which is still considered as normal in practice scenarios.

#### 4.3.3. Battery energy storage system

The backup support required from battery is 59.4 kW h, so a battery configuration that gives that amount of energy while operating at the inverter voltage of 48 Vdc is required. In addition, an industrial scale battery with at least 3500 cycles at depth of discharge DOD of 50 % was sought for. Based on this, Trojan IND17 − 6 V rated 6 V at 1202 Ah was selected, which gives 6 V × 8 = 48 V when arranged in series. The power derivable from the battery bank is 1202 × 6 × 8 × 0.92 = 53.08 kW h, as obtained previously. It should be noted that the DOD of a storage battery is typically defined as the capacity in ampere-hours that is discharged from a fully charged battery divided by nominal battery capacity. A battery with a DOD of 0% simply means that it is 100 % charged while the battery is completely flat when the DOD is 100 % (Hlal et al., 2019).

#### 4.3.4. Charge controller sizing

The charge controller has been so designed to minimize gassing and charging losses of the batteries. This is achieved by slowing the charging rate as the batteries approach fully charged condition. Charge controllers also protect the batteries from overcharging by completely disconnecting the PV array at some predetermined battery voltage, usually around 14 V (for a 12-V battery) or 28 V (for a 24-V battery). They also keep the batteries from being overly discharged by disconnecting the load when battery voltage drops below another set point, usually around 11.5 V or 23 V respectively.

To avoid over-charging the batteries, the critical factor is the maximum total current expected from the solar panels, given as:

$$Current,\ I = \frac{300 \times 80 \times 0.8}{48} = 400\,A$$

Therefore, six 60-A charge controllers operating at peak voltage of 150 V were selected.

### 4.4. Installation and commissioning of the PV energy system

Once the funds became available in September 2017, a meeting was held with the community members on land allocation and proper necessary documentations were carried out. The communities were also given orientation on proper use of electricity. After the exercise, land clearing and marking began on 17th September, 2017.

The four solar arrays to accommodate each of the PV panels, shown in Fig. 4, were constructed by September ending, while the power house and perimeter fencing were carried out in October of the same year. Mounting and bolting of the solar panels were done in November. The control equipment arrived also in November and by the beginning of December, wiring and installation commenced. By 17th December, 2017, light was switched on at Lajolo community to test-run. Distribution of power immediately commenced using 70 mm bare aluminum cables to different parts of the village.

#### 4.4.1. Installation of electric poles

Having completed the installation of the solar PV array and the control system, the erection of mechanical support and installation of appropriate insulators for the distribution of power was carried out as depicted in Fig. 5. This involves measurement and marking of the pole location, digging of the holes and erection of the poles. After this was

**Fig. 4.** Installed solar PV arrays.

**Fig. 5.** Single-phase power distribution system.

**Fig. 6.** Energy storage and control system.

**Fig. 7.** Overhead water storage tanks for irrigation purpose.

accomplished, two sets of aluminum conductors for live and neutral were mounted on the poles such that the all the household within the community could access electricity. Illustrated in Fig. 5 is the single-phase distribution system used to connect the customers to the power house.

Shown in Fig. 6 is the control room of the power house, which comprises inverter, charge controllers, storage batteries, distribution board, etc. The room, dimensioned 14 × 14 $ft^2$, is spacious enough to accommodate the components and equipment with adequate ventilation. A 2-HP split-unit air-conditioner is provided in the room to provide the necessary cooling of the components.

### *4.4.2. Motorized borehole for irrigation purpose*

One of the motives behind this project was to bring electricity to the communities for commercial applications to develop the economy of the area. To enhance the primary vocation of farming in the communities, a motorized borehole water for irrigation was sunk to enable them farm all year round. This really excited them as there was a provision for soft loan to enable them gets their inputs for farming. Shown in Fig. 7 are overhead tanks for water storage for irrigation purpose in the villages.

### *4.4.3. Metering of the customers*

Digital prepaid meters with ability to detect tampering were installed in customers' premises and activated using the codes provided by the vendor. To protect the customers from overloading the system, a cutout fuse of 5A rating is used to limit each household maximum power demand to 1 kW. In addition, an original Schneider 10-A circuit breaker is installed with each meter, for overload protection. Energy

**Fig. 8.** Prepaid Energy Meter, a Switch and a Lighting point in a customer's building.

tokens are sold to customers that have been connected to the microgrid. Fig. 8 shows an installed prepaid energy meter on a customer building.

## 5. Social and economic impact of the project on the communities

The project was completed and commissioned in January 2018. On seeing electric lights in their respective homes, members of the communities were very excited as they never imagined such development could take place in the nearest future. No doubt, the project has greatly enhanced the social and economic life of the people. With provision of street lights, the people now stay out late in the night to interact and do business. This has equally increased the security of the communities at night. Two women in the village have immediately commenced new businesses of freezing soft drinks and iced block. Our interaction revealed that many more villagers are willing to follow suit. The people that used to trek as far as 3 km away to charge their hand phones, now relax at home to do that conveniently.

## 6. Conclusion

This article has presented the design and execution procedure of the photovoltaic microgrid system carried out at Lajolo Community and its neighbouring communities in Nigeria, aimed at providing electricity at affordable rate to the remote area. The project was co-sponsored by Shaybis Nigeria Ltd (SNL) and IEEE Smart Village and executed in collaboration with the Advanced Power and Green Energy Research group, Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria. The project, which was commissioned in January 2018, has greatly improved the economic activities and social life of the beneficiary communities. The project also increased the security of the communities at night. With the provision of a motorized borehole for irrigation system, the villagers, who are predominantly farmers, can now farm all year round with bumper harvest.

## References

Abdulkarim, A., Faruk, N., Oloyede, A., Olawoyin, L., Popoola, S., Abdullateef, A., et al., 2018. State of the art in research on optimum design, reliability and control of renewable energy microgrids. ELEKTRIKA J. Electr. Eng. 17 (3), 23–35.

Akorede, M.F., Hizam, H., Pouresmaeil, E., 2010. Distributed energy resources and benefits to the environment. Renew. Sustain. Energy Rev. 14 (2), 724–734.

Akorede, M.F., Ibrahim, O., Amuda, S.A., Otuoze, A.O., Olufeagba, B.J., 2017. Current status and outlook of renewable energy development in Nigeria. Niger. J. Technol. 36 (1), 196–212.

Araki, I., Tatsunokuchi, M., Nakahara, H., Tomita, T., 2009. Bifacial PV system in Aichi Airport-site demonstrative research plant for new energy power generation. Sol. Energy Mater. Sol. Cells 93 (6–7), 911–916.

Barnes, M., Dimeas, A., Engler, A., Fitzer, C., Hatziargyriou, N., Jones, C., Vandenbergh, M., 2005. Microgrid laboratory facilities. In: IEEE Future Power Systems,

International Conference on. Amsterdam. pp. 1–6.
Council, W.E., 2013. World Energy Scenarios Composing Energy Futures to 2050. PSI, London.
Hatta, H., Kobayashi, H., 2007. A study of centralized voltage control method for distribution system with distributed generation. In: 19th International Conference on Electricity Distribution. Vienna. pp. 1–4.
Hatziargyriou, N., 2014. Microgrids: Architectures and Control. John Wiley & Sons.
Hlal, M.I., Ramachandaramurthy, V.K., Sarhan, A., Pouryekta, A., Subramaniam, U., 2019. Optimum battery depth of discharge for off-grid solar PV/battery system. J. Energy Storage 26, 100999.
Keeyoung, N., Jongbo, A., Heungkwan, C., Seulki, K., Jongyu, K., Changhee, C., Jinhong, J., 2009. Establishment of a pilot plant for KERI microgrid system based on power IT development program in Korea. In: Transmission & Distribution Conference & Exposition: Asia and Pacific. Seoul, South Korea.
Kim, J.-S., So, S.M., Kim, J.-T., Cho, J.-W., Park, H.-J., Jufri, F.H., Jung, J., 2019. Microgrids platform: a design and implementation of common platform for seamless microgrids operation. Electr. Power Syst. Res. 167, 21–38.
Krishnamurthy, S., Jahns, T., Lasseter, R., 2008. The operation of diesel gensets in a CERTS microgrid. IEEE PES General Meeting—Conversion and Delivery of Electrical Energy in the 21st Century 1–8.
Kroposki, B., Lasseter, R., Ise, T., Morozumi, S., Papatlianassiou, S., Hatziargyriou, N.A., 2008. Look at microgrid technologies and testing projects from around the world. IEEE Power Energy Mag. 40–53.
Lidula, N., Rajapakse, A., 2011. Microgrids research: a review of experimental microgrids and test systems. Renew. Sustain. Energy Rev. 15, 186–202.
Masters, G.M., 2013. Renewable and Efficient Electric Power Systems. John Wiley & Sons.
Miketa, A., Saygin, D., Ferroukhi, R.G., Hawila, D., Kojakovic, A., Nagpal, N., et al., 2015. Africa 2030: Roadmap for a Renewable Energy Future. IRENA, Abu Dhabi.
Mitra, I., Degner, T., Braun, M., 2008. Distributed generation and microgrids for small island electrification in developing countries: a review. SESI J. 18 (1), 6–20.
Morozumi, S., Nakama, H., Inoue, N., 2008. Demonstration projects for grid-connection issues in Japan. Elektrotechnik Informationstechnik 125 (12), 426–431.
Oseni, M.O., 2012. Improving households' access to electricity and energy consumption pattern in Nigeria: renewable energy alternative. Renew. Sustain. Energy Rev. 16 (6), 3967–3974.
Sandia National Laboratories, 1995. Stand-Alone Photovoltaic Systems Handbook of Recommended Design Practices.
Sendy, A., 2017. Pros and Cons of Monocrystalline vs Polycrystalline solar panels. retrieved January 29, 2019 from. https://www.solarreviews.com.
Webb, S., 2014. Renewable Energy in the Asian Pacific. DLA Piper, New Zealand.
Zervos, A., 2015. Renewables 2015 Global Status Report. global future reports (GFR), Paris.
World Bank, 2017 Access to electricity by population retrieved March 9, 2020 from https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=NG.

**T.Y. Salihu** earned his HND in electronics from Kwara State Polytechnic, Ilorin, 1987; his B.Eng. degree in electrical engineering from the University of Port Harcourt, in 1994; and his MTech degree in Power Systems Engineering from Rivers State University, Port Harcourt, Nigeria. He worked as Boiler Services Engineer at Waska Engineering, Benin and then proceeded to work for the Xerox Nigeria Ltd, where he rose to the position of Service Manager. He left Xerox in 1998 to venture into private business, from where his companies did a number of ICT and power solution projects for a number of organizations such as NNPC, British Council, Ecobank and son. In collaboration with IEEE SV in 2016 he started developing off-grid power solutions using renewable energy for forgotten rural populations, with special emphasis on Kwara State. He was among the team that restarted IEEE in Nigeria in 2000 and subsequently became the Nigeria section Chair 2006-11, MDO 2006-17 and currently co-ordinates the IEEE PES in Africa. He initiated the flagship conference of IEEE Nigeria. Tunde is a senior member of IEEE and a trustee of IEEE Nigeria.

**M.F. Akorede** received his B.Eng (Hons) in Electrical Engineering from University of Ilorin, Ilorin, in 2000 and M.Eng in 2006 from Bayero University Kano; both in Nigeria. He bagged his Ph.D. in Electrical Power Engineering from Universiti Putra Malaysia in 2011. Dr. Akorede is currently an Associate Prefessor in the Department of Electrical & Electronics Engineering, University of Ilorin, Ilorin, Nigeria. Presently, Dr. Akorede is the Managing Editor, Nigerian Journal of Technological Development, published by Faculty of Engineering and Technology of his university. He is Senior Member, IEEE and past Vice Chair, IEEE PES, Nigeria Section. He is also the Head, Advanced Power and Green Energy Research Group in his Department. His research interests include optimization of distributed energy resources in power systems, smart grid, microgrids, power system analysis, etc. Dr Akorede won the Best Researcher of the Year 2018/2019 Award at University of Ilorin, Nigeria.

**A. Abdulkarim** received his first degree at Bayero University Kano. He bagged his Master and PhD degrees at University of Ilorin, Nigeria and Queen Belfast University, UK, respectively. Dr. Abdulkarim was a lecturer at the Department of Electrical and Electronics Engineering, University of Ilorin. Presently he is a Senior Lecturer, Department of Electrical Engineering, Ahmadu Bello University, Zaria. He is Registered Engineer with Council for the Regulation of Engineering in Nigeria and member Nigerian Society of Engineers. In addition he is a member of IEEE and his research interests includes Renewable Energy, Reliability, Microgrids and Intelligent Control. Dr. Abdulkarim is the current Managing Editor Zaria Journal of Electrical Engineering.

**A.I. Abdullateef** earned his B.Eng in Ondo State University now Ekiti State University, Ado-Ekiti, in 1997 and M.Eng Degree in the University of Benin, Benin-City, 2004. He however proceded to International Islamic University, Malaysia for his PhD in Engineering. Dr Abdullateef is currently a lecturer I in the Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin Nigeria. He is a registered Engeer and his research interests include Power and Machines, Drives, Power system analysis, etc.