International Journal of Scientific Research and Engineering Development-– Volume 6 Issue 3, May-June 2023

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

# Investigation of Electricity Distribution Networks with Localised Energy Systems

Emmanuel Taiwo Fasina*, Bankole Adebanji**
*(Department of Electrical and Electronic Engineering, Ekiti State University, Ado Ekiti, Nigeria
Email: emmanuel.fasina@eksu.edu.ng)
** (Department of Electrical and Electronic Engineering, Ekiti State University, Ado Ekiti, Nigeria
Email :bankole.adebanji@eksu.edu.ng)

----------------------------------------************************----------------------------------

## Abstract:

This paper investigates the impact of localised energy systems on low voltage UK generic distribution network. Clusters of DGs and EVs were considered within three different Localised Energy Systems defined as LES1 with predominantly commercial load, LES2 with predominantly residential load and LES3 with a mixture of residential and commercial load. A load flow analysis was performed in a Neplan software environment to evaluate the network voltage changes, maximum allowable capacity of DGs, EV charging in each of the localised energy systems. The results show that in LES1 the customers could install a maximum of 264kW DG generation capacity; in LES2 the customers could install a maximum of 316kW DG generation capacity and in LES3 the customers could install a maximum of 149.6kW DG generation capacity to keep the network parameter within limits. In this way, the distribution network becomes reliable, efficient and secured.

*Keywords* —**Renewable energy, Distributed generation, Electric vehicles, Localised energy system, Power losses, Voltage profile.**

----------------------------------------************************----------------------------------

## I. INTRODUCTION

In the UK and Europe, localised energy system (LES) is widely regarded as one of the promising solutions to address the problem of lack of access to reliable electricity [1], [2],[3]. Localised energy system also known as decentralised generation is energy generated at or near the point of use. LES is defined as energy produced by generating plant of under 50MW connected to a local distribution network system, rather than to a high voltage transmission system [2]. Unlike centralised generation, they are connected close to the point of use which is responsible for losses reduction in the network with decentralised generation.

Localised energy systems are a key focus in the UK's power system revolution and are considered to facilitate greenhouse gas emission reduction [5],[6]. Cheaper electricity could be provided to the communities living close to this medium-sized electricity generation system [7], [8]. Most electricity distribution systems were designed for a one‐way flow of electricity. The addition of LES into the distribution system in increasing amounts might change the dynamic behaviour of the distribution systems by introducing new sources of energy that intermittently change the amount and direction of power flow in the grid [9] These changes in grid behaviour create new challenges for the utility in determining how to plan, design, and operate delivery systems that were not designed for the application of localised energy systems. Traditionally, voltage on a feeder is higher at the substation and will steadily decrease as electricity moves further from the substation [10]. This is due to the radial flow from the substation to the end usecustomer. With significant penetration of LES in the distribution system, the power flow in the distribution network may become reversed and result in a rise in voltage from substation to the end customers [9]. This power flow reversal depends on the relative magnitudes of the real and reactive network loads compared to the generator outputs. Effective integration of LES in the distribution networks requires effective planning with the aim of reducing the adverse impact on the distribution systems [9]. It is the obligation of the Distribution Network Operator to supply its customers at a voltage within specified limits. These specified voltage values vary from country to country. In the UK the electricity supply limit is +10% -6% of 230V [10]. The paper is organised as follows: Section I discuss the concept of localised energy system; Section II present the research methods and the network models; Section III discuss the simulation results, and conclusions are presented in Section IV.

## II. RESEARCH METHODS

The research method involves two processes namely data collection (from journal and internet) and system modelling. The system modelling consists of distribution system model without and with localised energy systems. A deterministic steady-state analysis was performed in order to assess a network's ability to accommodate LES technology. This is achieved by incrementally adding DG and EV units to the network for a given time period, i.e., maximum or minimum demand. In order to perform this analysis, a model of a section of UK LV distribution network was developed using power system analysis software (NEPLAN). Steady-state analyses were performed using unbalanced load-flow calculations, with the changes in voltage and thermal loading levels at various parts of the network recorded. The load-flow solutions were calculated using the Newton-Raphson method [11].

### *A. Power Flow Analysis*

The nodal equations used to analyse network are implemented using newton Raphson method. In the formulation, the nonlinear equations are solved by an iterative method. The power flow analysis calculates the power flows, voltage magnitude and phases for all nodes.

The current $I_i$ entering into bus i is given as

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \qquad j \neq i \qquad (1)$$

The real and reactive power at bus i is

$$P_i + jQ_i = V_i I_i^*$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (2)$$

Substituting for $I_i$ in (1) yields

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \qquad j =\neq \qquad (3)$$

From the above relation, the resulting algebraic non-linear equations must be solved by iterative techniques [11], [12].

Equation (3) above can be rewritten in terms of the bus admittance matrix as

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \qquad (4)$$

From equation (4), j includes bus i. expressing this equation in polar form, we have

$$I_i = \sum_{j=1}^{n} |Y_{ij}| \, |V_j| < \theta_{ij} + \delta_j \qquad (5)$$

The complex power at bus i is

$$P_i - jQ_i = V_i^* I_i \qquad (6)$$

Substituting from (5) for Ii in (6),

$$P_i - jQ_i = |V_i| < -\delta_i \sum_{j=1}^{n} |Y_{ij}| \, |V_j| < \theta_{ij} + \delta_j \; (7)$$

Separating the real and imaginary parts,

$$P_i = \sum_{j=1}^{n} |V_i|\,|V_j|\,|Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (8)$$

$$Q_i = \sum_{j=1}^{n} |V_i|\,|V_j|\,|Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \qquad (9)$$

Expanding (8) and (9) in Taylor's series results in set of linear equations. The element of the resulting Jacobian matrix are the partial derivatives of (7) and (8), evaluated at $\Delta\delta_i^{(k)}$ and$\Delta|V_i^{(k)}|$. It can be re-written as

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \qquad (10)$$

$\Delta P$ and $\Delta Q$ represents the difference between specified value and calculated value respectively. $\Delta V$ and$\Delta\delta$ represents magnitude voltage and voltage angle respectively in an incremental form.

### B. *Flow Chart for the Newton Raphson Methods*

The flowchart for power flow solution is presented in Fig. 1.

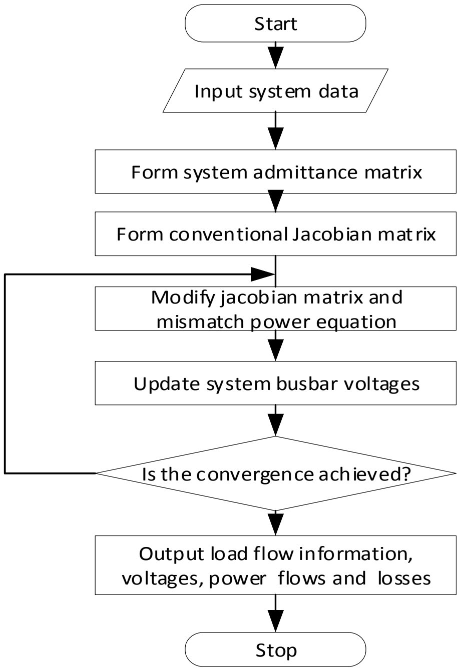

Fig. 1. Flowchart for power flow solution using Newton Raphson method [13],[14]

### C. *Power Losses*

The connection of DG in the distribution system will change the structure of power flow from radial to bidirectional [15], [16]. The integration of DG in the distribution system will cause reduction in the flow of current in the feeder which in turn reduces power losses. The magnitude of line losses depends upon the current flowing in the feeder and resistance in the line. The increase or decrease in losses is subject to the capacity of DG, its location, the load size and the network structure [17]. The real power loss in the network is given by Equation 11, also known as "exact loss formula" [18].

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iP_j)\right] \qquad (19)$$

where $\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$,

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j} = \sin(\delta_i - \delta_j)$$

and $r_{ij} + jx_{ij} = Z_{ij}$ are the $ij$th element of [Zbus] matrix

The effect of DG unit capacity can be studied by calculating the penetration level of DG unit. It can be mathematically represented as the function of total complex power supplied by a DG source over complex power peak load demand.Penetration level of DG is given by

$$P_{DG} = \frac{\sum S_{DG}}{\sum S_{Peak}} * 100\% \qquad (17)$$

The line losses in the system are related to the voltage profile [19].

### D. *Test System Descriptions*

The test system shown in Fig 2 is the UK generic network (UKGDN) model [20],[21].

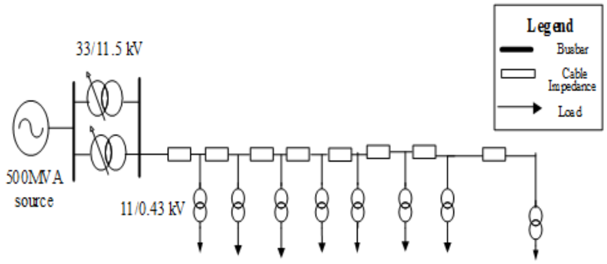

Fig 2 UK generic low voltage distribution network [20],[21]

It consists of a 500 MVA three phase 33kV ideal voltage source, connected to two 15MVA transformers, and eight 11kV outgoing feeder's substation. Each feeder supplies 11/0.433kV transformer which ultimately feeds the LES[20],[21]. Fig 2 is a low voltage distribution network that is used for this research.

### *E. Localised Energy Systems*

Three different localised energy systems were defined and modelled as LES1, LES2 and LES3 were defined and modelled for this study. The first localised energy system, LES1, is a residential distribution network with 384 homes with annual consumption of 4000kWh [21] as shown in Fig3.

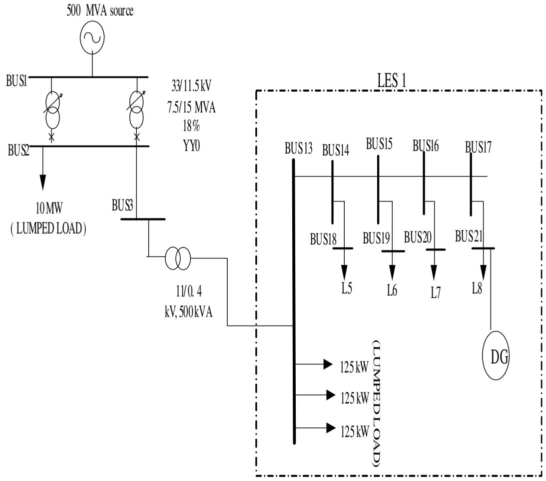

Fig 3. Distribution low voltage network with LES2

The second localised energy system, LES2, is a commercial distribution network with sixteen offices with a maximum and minimum loading of 19.275kVA and 5kVA as shown in Fig 4. The average office has a power factor of approximately 0.85 [21].

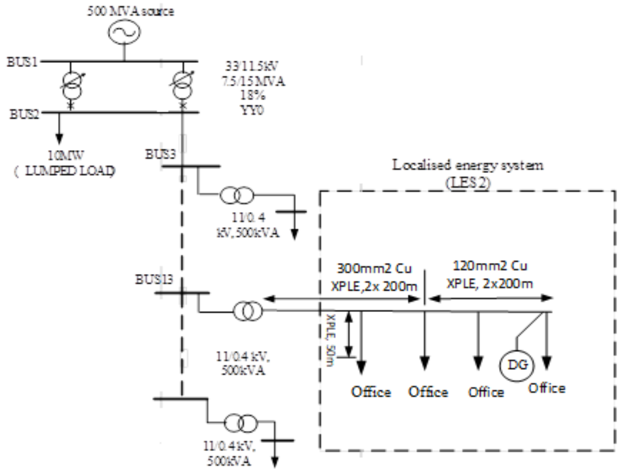

Fig 4. UK generic distribution network with LES2 [21]

The third localised energy system, LES3, is a housing estate, having 63 residential homes and 1 commercial building and is based on a real Cardiff network.

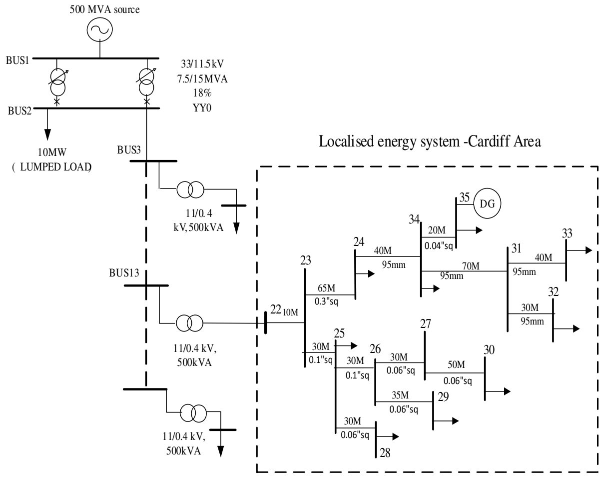

Fig 5. UK generic distribution network with LES3[21]

As shown in Fig 5 the network consists of 15 nodes and a 500kVA distribution transformer. The commercial load in the network is represented by node 35.

## IV. CASE STUDY

The case study analyse the impacts of localised energy systems on the low voltage UK generic distribution network with respect to the network voltage profile, network losses, transformer loading, maximum capacity (units) of DG that could be connected to the distribution system without violating the DNO permissible voltage limits of +10%/-6% based on 230V [22]. It is assumed that abasic unit of DG is 1.1kW for residential customers and 5.5kVA for commercial customers [20].

## V. RESULTS AND DISCUSSION

### A. Network Voltage Changes

The load flow analysis results for the three localised energy systems are shown in Fig 6 and Fig 7.

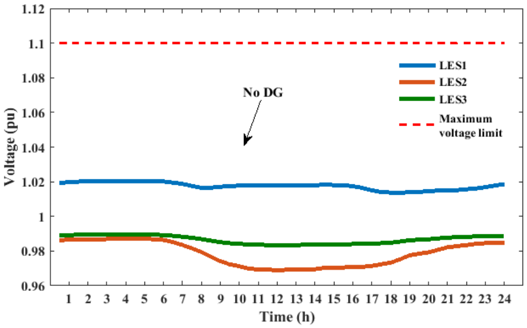

Fig 6. Voltage profile without distributed generation

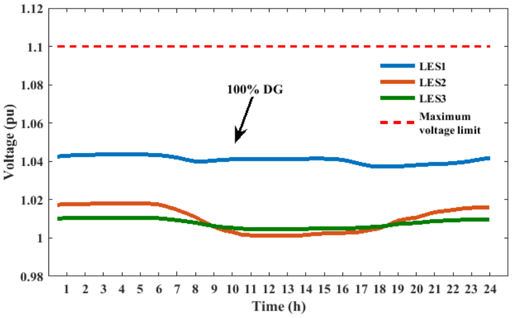

Fig 7. Voltage profile with Distributed generation

The graph in Fig 7 represents the normal voltage profile with distributed generation. The voltage profile at zero DG reflects the normal working voltage. The maximum voltage occurred in the LES1 followed by LES3. The residential customers consumed lesser load than other customers. However, the voltage in LES1, LES2 and LES3 are within permissible voltage limits of DNOs. The statutory voltage limit for low voltage levels being 0.404kV (0.94p.u.) and 0.473 kV (1.10p.u.) respectively. When DG was connected to the network, there is significant rise in voltage in all the localised energy systems. This rise in voltage is due to the DG power cancelling out some or all of the residential and commercial loads, and some due to excess generator real power flowing back through a mainly resistive network to the distribution transformer.

### B. Power Losses

In this case, two simulations were conducted with and without DG connected. Over the simulation time, the maximum network losses occurred in LES3 which is 20.36 kWh at 12:00. With DG connected, the losses reduced to 15.31kWh at 12:00. Without DG, from Fig11, it was shown that the total loss in the network was 935.1kWh. The losses reduced to 706.2kWh with DG connected to the distribution network. However, the lowest losses occurred at LES2 as shown in Table 1. The value reduced to 615.3kWh with 100% DG added to the network. The total loss reduction is 113.9kWh (15.61%).

Table 1. Network losses with and without distributed generation

| | **Power losses over the day (kWh)** | | |
|---|---|---|---|
| | LES1 | LES2 | LES3 |
| Without DG | 884.9 | 729.0 | 935.1 |
| With | 730.0 | 615.3 | 706.2 |

| DG | | | |
|---|---|---|---|

### C. Distribution Transformer Loading

The maximum power in MVA or the maximum current in Amp (A) must be known for the calculation of transformer loading. From Table 2, it is shown that in LES1, the transformer loading varies with time and increases as the customer's demand is increasedAs shown in Table 2, without DG, the maximum transformer loading in LES1 is 103.1% but reduced to 75.05% with DG connected.

Table 2. Maximum transformer loading

| | **Distribution Transformers loading** | | |
|---|---|---|---|
| | LES1 | LES2 | LES3 |
| Without DG | 103.1 | 96.27 | 91.85 |
| With DG | 75.05 | 61.21 | 52.21 |

In LES2, the transformer's loading reduced to 61.21% from 96.29% and in LES3 the transformer loading reduced from 91.85% to 52.21% for the 24 hours simulation time.

### D. Allowable DG capacity in the LES

As shown in Table2, each residential customer in LES1 can install three units of DG at maximum loading and one unit of DG at minimum loading. Whereas in LES2, each commercial customers can install four units of DG and during minimum loading condition each customer can install one unit of DG as shown in Fig8.

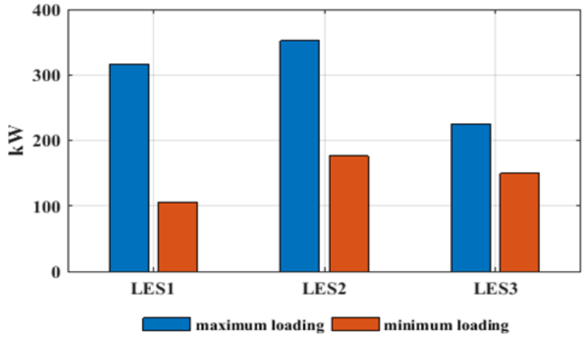

Fig 8. Maximum DG capacity installed in each LES

Also, the results show that in LES3, each of the 63 residential customers can install 3 units of DG at maximum loading condition of the distribution system while the commercial customer can install 3units of DG at the maximum loading condition.

However, at minimum loading, each residential customer can install two units of DG and each commercial customer can install 2 units of DG at minimum loading.

### E. Electric Vehicles (EVs) Charging within the LES

The basic unit of EV is considered to be 6.6kW for residential customers [22] and for commercial load a car park with 40 EVs is considered as 100% penetration. The EV is considered in Grid to Vehicle (G2V) mode [23]. The results show that a total of forty-eight customers in LES1, eighty customers in LES2 and thirty-two customers in LES3 can charge their EVs without violating permissible voltage limit.

Table 3: Total number of EVs that could be charged

| **Total number of EVs that could be charged within LES** | | |
|---|---|---|
| LES1 | LES2 | LES3 |
| 48 | 80 | 32 |

## 5.0 CONCLUSSION

The impact of localised energy systems on the UK generic distribution systems have been analysed and identified. The results show that the third localised energy system (LES3) with commercial load caused the greatest impact on the network with respect to voltage changes and network losses due to high electricity demand. Therefore, large reinforcements will be necessary to mitigate this adverse impact which are most costly. Whereas, the first localised energy system (LES1) has a relative low impact on the distribution network since majority of residential customers consume very low electricity. Localised energy systems are located very close to the loads, which prevent a large amount of power flowing from the substation to the loads leading to low network losses. Also, at higher penetration of LES, the generated excess power outside of the peak demand will be fed back into the grid. If the excess power is not consumed by other consumers during the peak demand periods a voltage rise occurs. This voltage rise may have adverse effects on consumer appliances. In order to mitigate this problem voltages control strategies such as, active power curtailment, smart grid design and implementation and reactive power compensation are employed.

Therefore, prior to LES integration, a comprehensive study must be carried out to determine the electricity consumption pattern of the customers for safe network operation. The results of the research on the UK network are relevant in Nigeria and other developing countries in sub-Sahara Africa where power consumers are located mostly far away from the centralised generations. DG used in this study is solar PV as such would help to achieve CO2 emission target. As a result, in the past decade many large-scale plants have been commissioned. However, such plants are mostly done without prior technical studies to find out what impact such integration has on the national grid. Thus, this paper is considered a reference for engineers, grid operators, and investors to consider when a grid impact study is required.

## REFERENCES

[1] G. Artizzu., A. Paola., E. Patriarca, “Decentralized renewable energy solutions to foster economic development,” *Renew. Energy Solut. Africa*, 2017.

[2] Greenpeace, “Decentralising power : an energy revolution for the 21st century,” 2005.

[3] P. Wolfe, “The implications of an increasingly decentralised energy system,” *Energy Policy*, vol. 36, pp. 4509–4513, 2008, doi: 10.1016/j.enpol.2008.09.021.

[4] International Energy Agency (IEA), “Energy and climate change,” *World Energy Outlook Spec. Rep. OECD/IEA PARIS*, 2015.

[5] B. Woodman and P. Baker, “Regulatory frameworks for decentralised energy,” *Energy Policy*, vol. 36, pp. 4527–4531, 2008, doi: 10.1016/j.enpol.2008.09.017.

[6] Local Energy Systems, *Siemens UK*. [Online]. Available: https://www.siemens.com/content/dam/webassetpool/mam/tag-siemens-com/smdb/regions/united-kingdom/energy-management/local-energy-systems-uk-brochure.pdf. [Accessed: 25-Jun-2018].

[7] House of Commons, “Local Energy,” *Sixth Rep. Sess. 2013–14 Energy Clim. Chang. Comm.*, vol. VolumeI, 2013.

[8] House of Commons, “Local Energy,” *Sixth Rep. Sess. 2013–14 Energy Clim. Chang. Comm.*, vol. Volime II, 2013.

[9] Fasina E.T., Adebanji B,Abe A, and Ismail I. Impact of Distributed Generation on the Nigerian Network. Indonesian Journal of Electrical Engineering and Computer Science 2020; 21(3): 1263-1270

[10] N. Jenkins, J. B. Ekanayake, and G. Strbac, *Distributed Generation*, Renewable Series IET, London, UK, 2010.

[11] H. Saadat, *Power System Analysis*, Third Edition, PSA Publishing, 2002.

[12] P. Kundur, *Power System Stability And Control*. Englewood Cliff, NJ: McGraw-Hill, Inc., 1994.

[13] E.T. Fasina, A.S. Hassan, L.M. Cipcigan, "Impact of localised energy resources on electric power distribution systems. *2015 50th International University Power Engineering Conference*, pp. 1–5, 2015, doi: 10.1109/UPEC.2015.7339793.

[14] E. T. Fasina, R. O. Oliyide, and L. M. Cipcigan, Localised energy systems in Nigerian power network, in *Proceedings - 2017 IEEE 15th International Conference on Industrial Informatics, INDIN 2017*, 2017, pp. 456–461, doi: 10.1109/INDIN.2017.8104815.

[15]N. Rugthaicharoencheep, and S. Auchanyamet, “Technical and economic impacts of distributed generation ondistributed system, *World Academy of Science, Engineering and technology, vol6, no.4,*pp. 254-258, April 2012.

16] N. Acharya, P. Mahat, and N. Mithulananthan, “An analytical approach for DG allocation in primary distribution network,” Elsevier Electrical *Power and Energy Systems*, pp. 669-678, Dec2006.

[17] S.M. Moghaddas-Tafreshi, and E. Mashhour, “Distributed generation modeling for power flow studies and three-phase unbalanced power flow solution for radial distribution systems considering distributed generation,” *Elsevier Electric Power Systems Research, vol. 79, no.4.* pp. 680-686, April 2009.

[18] V. Cosentino, S. Favuzza, G. Graditi, M.G. Ippolito, F. Massaro, E.R. Sanseverino, and G. Zizzo, “Smart renewable generation for an islandedsystem. Technical and economic issues of future scenerios,” Elsevier Sustainable Energyand Environmental Protection, vol. 39, pp.196-204, March2012

[19] L.F. Ochoa, and G.P. Harrison. “Minimising energy losses: optimal accommodation and smart operation of renewable distributed generation,” *IEEE Trans. Power systems, vol.26, no. 1, pp. 198-205,* February 2011.

[20] S. Ingram, S. Probert, and K. Jackson, “The Impact of Small Scale Embedded Generation on the Operating Parameters of Distribution Networks,” *DTI New Renew. Energy Program.*, pp. 1–145, 2003.

[21] E.T Fasina “ Localised Energy Systems in the Nigerian Power Network,” PhD Thesis submitted to Cardiff University, 2019.

[22] Department of Trade and Industry, “Guidance on The Electricity Safety, Quality and Continuity Regulations 2002,” *Rep. Number URN 02/1544*, no. October, pp. 1–47, 2002.

[23] P. Papadopoulos, S. Skarvelis-Kazakos, I. Grau, L. M. Cipcigan, and N. Jenkins, “Electric vehicles’ impact on British distribution networks,” *IET Electr. Syst. Transp.*, vol. 2, no. 3, p. 91, 2012, doi: 10.1049/iet-est.2011.0023.