The Economic Implication of Optimal Sizing of DG for Power Quality Improvement of Distribution Network in Nigeria

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Abstract—This paper assesses the economic implication of optimal sizing of Distributed Generator in power distribution network. The Point of Common Coupling (PCC) are suppliers’ responsibility and customers demand meet, line loss and fault limits of the distribution network are of great concern due to increase degree of voltage variation assessment; valuable indicator of system conditions (voltage profile). Unstable condition of the power system outside operational or statutory limit, an adverse effect of nonlinear loads usually generate harmonics as well as fundamental frequency voltage variations and increase rate of power losses. The major concerns of utility operations are to mitigate adverse effect of this system conditions. This paper work focuses on optimal siting and sizing of Distributed Generation (DG) in a 43-bus distribution system. Power losses coupled with voltage deviation, considering objective function that computes present percentage losses in 11kV Dikko feeder, Abuja Electricity Distribution Company (AEDC), Suleja Distribution Network, Nigeria. Genetic Algorithm Optimization techniques programmed in MATLAB 2015 software was used for optimal placement and sizing of the DG in the system. This paper reveals the economic benefit on placing DG in power distribution network with annual saving of ₦4,187,282.69k. It is observed that 8.10% and 7.20% active and reactive power loss reduction was achieved while bus voltage improved by 0.4%.

Index Term—Distributed Generation, Genetic Algorithm, Optimal Placement, Power loss reduction, Voltage Profile Improvement.

I. INTRODUCTION

In developing countries like Nigeria, the adoption of DG is highly considered in a different context. The grid electric power system consists of Generation, Transmission, Sub transmission and Distribution. Bulk power supply refers to generation and transmission while final means of electric power release to consumer are sub transmission and Distribution. The Distribution delivers electric energy to end-user [1].

The Distribution system affects the consumers due to differences in amount of power delivered to them when compared to generate quantity of power because of long distance between the generating stations and load centers. The difference shows that there are losses along the lines. These losses can be classified as technical losses: No load losses (transformer magnetizing current etc.), Load losses (FR losses), Reactive losses (poor power factor, transformer reactive losses), Regulation (voltage drops) and Non-technical or commercial losses (illicit connection, or poor metering) [1].

Application of on-site measurements of feeders’ losses is found to arrive at a careful quantification of energy used and total losses. ETAP load flow studies are made to compute technical losses. In Nigeria, distribution networks are fragile and characterized by voltage variations: voltage dip, flickers, and line losses. It is absolutely imperative to reduce these losses and improve its overall efficiency centered at supply quality and reliability. Hence, the basis of this research work. Therefore, on acceptable limit of percentage losses be given adequate attention [2].

The research work is to focus and come up with a way of sustainably reducing power losses in the distribution network at the Point of Common Coupling (PCC) where the customers ‘demand and supplier of electricity responsibilities meet. A good number of (authors, researchers, engineers, etc.) seem to agree with at least Small-scale generation units connected to distributed grid as part of distributed generation [3].

Distributed generation may further be defined as sources of electric power generation connected directly to customer side of the meter or the distribution network [3]. According to [4] they proposed the application of Genetic Algorithm or particle swarm optimization to find the correct placement and size of 3 DG units in a 38 – bus network. In related development, [5] deployed Ant Colony Search Algorithm (ACSA) Software or optimal siting and sizing of multiple DG to obtain power loss reduction from 0.224MW loss to 0.083MW loss and voltage improvement programmed in MATLAB.

Similarly, in [6] Wind turbine generator was modeled by application of Dig – SILENT power factory software to show the impact of DG on distribution losses and the result gotten revealed that technical losses have reduced from 0.06MW to 0.03MW about 50% reduction when DG was sited on another bus about 67% reduction at 0.02MW. Likewise, [7] Applied Genetic Algorithm for optimal DG siting, voltage profile improvement and loss reduction in distribution network system was effective. The method was programmed in MATLAB software and they used ETAP Application software for evaluating result correctly.

Again [8] proposed modified Bat Algorithm for power loss reduction in electrical distribution system tested on 33-bus system and the result shows loss reduction rate of 33%.

Also [9] showed Genetic Optimization Algorithm for optimal placement and sizing of distributed generation units in residential distribution grid was effective.
Furthermore, [10] deployed Particle Swarm Optimization (PSO) techniques to achieve line loss reduction and optimal DG placement was considered in distribution system using wind turbine generator when compared with heuristic method are accurate in finding optimal DG siting whereas Analytical methods compares small error in DG size decision. The change in voltage profile before and after optimal DG placement was considered by application of heuristic techniques like PSO to eliminate even the smallest possible error.

In [11], A Fuzzy interface system (FIS) technique to optimize DG placement in a way to obtain power loss reduction from 194.25KW before DG siting to 110.28KW when DG was installed and voltage level improvement.

In related development [12] Applied Artificial Bee Colony search algorithm to obtain its optimal placement and minimum number of DG units in a way to minimize the real power loss in a network. For the IEEE – 69 bus feeder was tested by the authors using Artificial Bee Colony search algorithm. The proposed algorithm resulted in the same solution exactly as the exact method.

Also, [13] Applied modeling on a distribution network and Differential Evolution for Optimization. Assessment and physical investigation and analysis of an existing distribution network feeder as primary target of their work whilst Genetic Algorithm was used to optimize DG siting, which resulted a loss reduction of 47.3%. Therefore, based on the literature review, this research work intends to actualize genetic algorithm optimization techniques for optimal sizing and siting of distributed generation for power quality improvement on distribution network.

Optimal sizing and siting of Distributed Generation (OSSD) problem in distribution networks system is of two perspectives. Firstly, Distributed Generation (DG) units that needs to be optimized. There is investment decision with respect to single or multi-objective point of view that can be quantified numerically [14].

Considering the imposed operational constraint by the technologies and power network to be installed and according to the classical economic dispatch on power generation problem the newly installed DG units operation is also optimized [15].

Considering, 132/11kV distribution network consists of at least one or more power transformer substation installed, which radiate 11kV feeders that supply consumers need at the point of common coupling see figure 1.

This modeling is aimed to enable prediction of the effected changes DG has on the system adequately. Network Modeling of Dikko feeder was done in ETAP [17] with all data collected and input for the analysis of the network.

The distance between any of the two distribution transformers in the network, represents the length of distribution lines, this is used in ETAP application for network modeling. ACSR conductor was selected as conductor type used in 11kV distribution network. In the ETAP in-built conductor library, all required and available cable specifications for conductor modelling were chosen. The 11kV down dropper cable (XLPE) used contained in ETAP cable library with technical details were considered. Figure 1 shows the Dikko feeder modeled in ETAP [17].

II. METHOD OF DATA COLLECTION

Various sources of data were identified both internal and external sources. Internal sources include hand over notes, written policies, distribution network design etc. External sources are distribution transformer manufacture nameplate, on-line, suppliers and contractors document.

A. Equipment Used

Set of equipment were deployed to observe real-time and long-term readings and also to collect data for downloading to computer for analysis.

1. ‘Clamp meter’ was used to take distribution transformers reading.
2. Portable ‘Data Logger’ was also used to monitor many of the same parameters as the power quality analyzer.

These equipment were used to measure variety of parameters; voltage, amperage, frequency, power factor and the resulting power.

Direct observation and telephone call techniques were also employed. Percentages loading on 11/0.415kV distribution transformers were collected from AEDC Suleja, Office, Nigeria.

\[ I_T = I_R + I_Y + I_B \]  \hspace{1cm} (4)

Where,

- \( I_T \) is the Total current
- \( I_R \) is the current on red phase
- \( I_Y \) is the current on yellow phase
- \( I_B \) is the current on blue phase

\[ P = \sqrt{3}VI \]  \hspace{1cm} (5)

Where,

- \( P \) is the power rating of the transformer.
- \( V \) is the voltage of the transformer secondary.
- \( I \) is the current of rated transformer secondary.

\[ \text{Transformer % loading} = \frac{R_Y + B}{R_{sec} \times 100} \]  \hspace{1cm} (6)

Computation of the Transformer ratings, voltage ratio (11/0.415kV) and impedances for all distribution transformers were done in ETAP environment coupled with the other technical information required which are embedded in the software library were also selected [16,17].
B. Objective Function

The objective function of this research is to minimize the power losses and improve the voltage profiles across the line length of the distribution network [18].

The objective function represents the total loss on the system that can be expressed by the branch resistance $R_i$ active and reactive power $(P_i, Q_i)$ and bus voltage $V_i$.

(a) Power losses reduction
(b) Improvement of voltage profiles

\[
\text{Losses}_{\text{withDG}} \leq \text{Losses}_{\text{withoutDG}}
\]

Note: $P_{loss} = I^2R$  

Where,

- $P_{loss}$ is the power loss
- $I$ is the line current
- $R$ is the line resistance

\[
I = \frac{P_i^2 + Q_i^2}{V_i^2}
\]

Where,

- $P_i$ is the active power losses;
- $Q_i$ is the reactive power losses;
- $V_i$ is the bus voltage

\[
f = \max\text{LLR}\% = \frac{\text{LL}_{WODG} - \text{LL}_{WDG}}{\text{LL}_{WDG}} \times 100
\]

Where,

- $\text{LL}_{WODG}$ is the line loss with DG, pu;
- $\text{LL}_{WDG}$ is the line loss without considering DG, pu;
- $R_l$ is the line resistance of line l, pu/km;
- $D_l$ is the line length of line in km;
- $I_{WDG}^l$ is the current value of line l in pu before DG installation;
- $I_{L,WDG}^l$ is the current value of line l in pu after DG installation [19].

(a) Voltage deviation

\[
VD_i = |1 - V_i|
\]

Sum of voltage deviations

\[
SVD_i = \sum_{l=1}^{n} |1 - V_i|
\]

Where $V_i$ is the Voltage at Bus i and n is the number of buses

Considering a permissible limit of voltage deviations ±5% (0.95 ≤ $V_i$ ≤ 1.05 p.u)

C. Distributed Generation Optimization Constraint

To have a secure and stable operation, the active power supplies to the network should be restricted from back feeding to the substation, to avoid fault in the networks unnecessarily.

(a) Power Injection Constraints;

\[
\sum_{i=1}^{n} P_{DG} < P_{load} + P_{losses}
\]

(b) Total Power Balanced Constraint

\[
\sum_{i=1}^{n} P_{DG} + P_{substation} = P_{load} + P_{losses}
\]

Where,

- $P_{DG}$ is the power supply by DG
- $P_{substation}$ is the power supply from substation
- $P_{load}$ is the power supplied to connected loads on the network
- $P_{losses}$ is the power losses on the network
- n is the number of distributed generators connected

(c) Total number of DG

Number of DG ($N_{DG}$) must be less than or equal to maximum number of DG ($N_{DG/\text{MAX}}$)

\[
N_{DG} \leq N_{DG/\text{MAX}}
\]

(d) DG generation capacity constraint

The active power at each DG ($P_{ga}$) is limited by its upper and lower limits.

\[
P_{ga_{\text{min}}} \leq P_{ga} \leq P_{ga_{\text{max}}}
\]

(e) Voltage and current constraint

The Voltage magnitude at each bus and the current magnitude of a feeder must satisfy permissible limit as follows

\[
V_{min} \leq |V_i| \leq V_{max}
\]

\[
|I_j| \leq I_{j\text{max}}
\]

Where,

- $|V_i|$ is the voltage magnitude of node I,
- $V_{min}, V_{max}$ is the maximum and minimum voltage limits, respectively
- $|I_j|$ is the current magnitude of each line j,
- $I_{j\text{max}}$ is the maximum current limit of line j [19,20]
D. State of DG and Capacity

Each generator is represented by binary bits of 9 with a string, named Y. The string consist of three (3) parts, the first bit (part 1) represent the state of the generator (0 for off and 1 for on) the remaining 8 bits (part 2 and 3) represent the power level of the generator, the first 4 bits (2nd to 5th) represented the active power of DGs and the second 4 bits (6th to 9th) represent the reactive power of DGs [20].

![Fig. 2. Single Line Diagram of the Dikko feeder modeled in ETAP.](image)

\[
Y = [000000000]
\]

Fig. 3. chromosome of a generator not existing or not operating (Off)

\[
Y = [111111111]
\]

Fig. 4. chromosome of a generator working at full capacity (On)

\[
Y = [110100011]
\]

Fig. 5. chromosome of a generator working at active power capacity of 33.33% and reactive power capacity of 80%.

E. DG Placement

Each string Y is a representation of generator size to be place at a given node. This placement location representation is straightforward over the network. A string Z directly defines the concatenation of (Y x No of nodes), bits. The system contains 43 nodes. The number of bits is equal to nodes number (43 x bits per node (9) = 387 bits. Any string of Z describes a valid placement and size configuration of generator at a particular network system. Therefore, the chromosome used within GA is Z.

For 43 bus test system of 11KV Dikko feeder, chromosome Z is presented in figure 3.5 where some generators are Off or On that implies that some buses don’t need any DGs whereas buses which chromosomes first bit is one (1) e.g. Y1 and Y43 the DG should be located and it is possible to compute reactive power and the real power by using remaining 8 bits the first 4 bits (2 to 5) used to calculate real power while 4 other bits (6 to 9) used for reactive power calculations (see fig. 6).

![Fig. 5. showing chromosome Z.](image)

III. RESULT AND DISCUSSION

In this research work, distribution network was modeled and simulated using ETAP version 12.6. A genetic algorithm optimization technique was deployed to actualize optimal sizing and siting of DG, programmed in MATLAB to meet objective function centered at enhancing power quality, which was tested on 43 Bus systems by installing DG at best, locations.

Table I illustrate summary of results obtained from Load Flow Analysis carried out on Dikko Feeder without DG connection to the network.
Table I
Load Flow result summary of Dikko Feeder without Distributed Generator

<table>
<thead>
<tr>
<th>Active Power Losses (Kw)</th>
<th>Reactive Power Losses (kVar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>246.300</td>
<td>289.903</td>
</tr>
</tbody>
</table>

Table II shows summary of results obtained from Load Flow Analysis carried out on Dikko Feeder with DG connection to the network.

Table II
Load Flow result summary of Dikko Feeder with Distributed Generator

<table>
<thead>
<tr>
<th>Active Power Losses (Kw)</th>
<th>Reactive Power Losses (kVar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>226.356</td>
<td>267.040</td>
</tr>
</tbody>
</table>

The single Line diagram of the 11kV Dikko feeder modeled in ETAP, 43-bus system 1 X 50kVA, 5 X 100 kVA, 6 X 200 kVA, 10 X 300 kVA, and 21 X 500 kVA distribution transformers, shown in figure 2. The data of the system were obtained from AEDC, Suleja. The total load of the system was considered as (3490 + j2700) kVA and total active and reactive power losses in the system before DG installation were 289.903 kW and 269.040 kVAR respectively shown in Table I.

Table III shows result of power losses reduction for DG optimal placement Type 4 in the 43 Bus system.

Table III
Results of Power losses reduction for DG optimal placement

<table>
<thead>
<tr>
<th>Method</th>
<th>Bus No</th>
<th>DG Size (kW)</th>
<th>DG Size (kVar)</th>
<th>% Loss Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>analysis</td>
<td>1</td>
<td>54.00</td>
<td>37.37</td>
<td></td>
</tr>
<tr>
<td>GA</td>
<td>12</td>
<td>160.33</td>
<td>18.53</td>
<td>8.10</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>71.93</td>
<td>33.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>48.27</td>
<td>32.92</td>
<td></td>
</tr>
</tbody>
</table>

Optimum size and location of DGs in Type 4 for minimization and percentage loss reduction of losses were determined. Total, active and reactive power losses in the system after DGs installation in the case study is presented in this table. It can be seen from this table that determination of optimal sizing and siting of DGs for Power Quality improvement has a considerable effect on loss reduction in the network. It is observed in table 3 that 8.10% and 7.20% active and reactive loss reduction. These are represented with curves on figure 3 and 4.

It is observed that the percentage voltage losses before DG installation were more than those recorded compared to after DG installation. Adoption of DG on distribution network will reduce losses and save more to meet up with energy demand as shown if fig. 10,11, and 12.

Above 85% of buses were observed more than 6% permissible limit of voltage drop when the load flow analysis was carried out on Dikko Feeder without DG installation, however, there was non of the buses with voltage drop going above 4% after the DG installations and simulation on the same feeder. Hence, a considerable effect of voltage profile improvement was achieved.
The objectives of this research work were to estimate the economic benefit values of DG and to determine present percentage losses in the 11kV Dikko feeder, and it was discovered that 8.10% and 7.20% active and reactive loss reduction were achieved.

The voltage drops on Dikko feeder, BJY – Up BJY line and Tungan S1 Bus 2 has the poorest voltage profile, drop of 9.63%, this bus voltage improved to 0.4% drop when DGs were installed on the feeder.

Also, to determine optimal sizing and siting of DGs where losses can be mitigated and power quality improved, we were able to achieve DG sizes: 54 -j37.37, 160.33+j18.53, 71.93+j33.44, and 48.27+32.92 at buses 1, 12, 25 and 41 respectively.

The reduction of total active and reactive power losses from (246.300kW, 289.903kVAR) to (226.356kW, 267.040 kVAR) respectively was achieved. This represents about 8.10% and 7.20% reduction respectively.

### IV. CONCLUSION

REFERENCES


