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ENHANCED OPTIMAL SIZING AND SITING OF DISTRIBUTED GENERATION FOR POWER QUALITY IMPROVEMENT: A CASE STUDY OF SULEJA DISTRIBUTION NETWORK, NIGER STATE, NIGERIA

B. Abubakar, J. N. Emechebe & M. Uthman

Research Scholar, Electrical/Electronic Department, University of Abuja, Nigeria

ABSTRACT

The Point of Common Coupling (PCC) where supplier's responsibilities and customer's demands meet is of great concern. The generated quantity of electric power delivered to load centers of distribution systems from generating stations show differences; these differences are classified as technical losses. This research work presents Enhanced Optimal Sizing and Siting of Distributed Generation (DG) for Power Quality Improvement of Suleja Distribution Network. Electrical Transient Analysis Program (ETAP) load flows studies are made to compute the technical losses and application of Genetic Algorithm Optimization techniques programmed in MATLAB 2015 Software in 43- bus distribution system were used. The total load of the system considered as based case was (3490 + j2700) kVA. Active and Reactive power losses in the system before DG installations were 246.300 kW and 289.903 kVAR respectively. DGs installation in the case study, has a considerable effects on loss reduction in the network. It is observed that 8.10% and 7.20% for active and reactive power loss reduction respectively were achieved while bus voltage improved by 0.4%. These satisfied the objective functions that compute present percentage losses, identified buses with poor voltage profile and determination of optimal sizing and siting of DGs where losses can be mitigated and power quality improved.

KEYWORDS: *Power Quality, Suleja Distribution Network*

Article History

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INTRODUCTION

Electricity is a useful form of energy in the modern world; present social infrastructure economic growth and development in the country all need electrical energy. When switched on, it is transmitted almost with the speed of light. Electricpower consumption is increasing in the modern world thereby reflecting growing of living standard of populace. An effective Distribution system of the form of energy must be put in place to ensure maximum satisfaction and optimum utilization by society. 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 released 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 generated quantity of power because of long distance between the generating stations and load centers. The differences show that there are losses along the lines. These losses can be classified as technical losses: No load losses (transformer magnetizing current etc.), Load losses (I^2R losses), Reactive losses (poor power factor, transformer reactive losses), Regulation (voltage drops); and Nontechnical or commercial losses (illicit connection, or poor metering) [1]. Application of on-site measurements of feeder losses are found to arrive at a careful quantification of energy used and total losses. Electrical Transient Analysis Program (ETAP) load flow studies are made to compute technical losses. In Nigeria today most places experience poor voltage profile. Consumers that are far away from service transformer experience this poor voltage profile. Nigeria Electricity Distribution Companies have following voltage levels: secondary side 230V for single phase and 415V for three phases except few appliances that have switch mode power supply which convert 230V incoming to 12V or 24V required by the appliance. Presently the voltage of Nigeria Distribution Company can go as low as 160 – 180V and as a result electrical appliances get damaged and operational failures occurs as consequences of overheating [2].

Electrical design consideration of consumer loads are resistive and inductive in nature. Resistive loads generate no magnetic field and are without electric motor e.g. incandescent light bulb operate under wide range of voltages, however voltage variation (higher or low) affect the efficiency. Inductive load: AC Electrical load in which the current lags the voltage i.e. voltage waves reach the peak before the current. This simply means that electric motors are embedded in the design of an inductive load e.g. refrigerator, air conditioners, and pumps. Generally, in case of an adverse condition, the system tends to operate on low voltage and low frequency. Considering low voltage, different loads respond according to voltage variation. For every one percent drop in voltage, reduction in approximate wattage will be 1.6 %, in filament lamps, 1.4 % in fluorescent lamps and resistance loads of 2 %. Induction motors draw more current causing overheating, weakening of the motor insulation winding, short circuit and burning of the motor [1]. Low frequency affects the equipment performance by lowering speed, output, and efficiency of the motor. Decrease in speed results in poor ventilation and hence overheating.

These equipment need to be protected due to failure as the result of voltage variation: high voltage results in basic insulation breakdown and low voltage results in over heating due to excessive current drawn by the equipment that leads to failure. [1].

LITERATURE REVIEW

Optimal sizing and siting of Distributed Generation (OSSD) problem in distribution networks system is of two perspectives. Firstly, Distributed Generation (DG) units that need to be optimized; there is investment decision with respect to single or multi-objective point of view that can be quantified numerically, while considering the imposed operational constraint by the technologies. The decision concerning investment will result in installation of new DG units at optimal location in the power network. Secondly, in the power generation, newly installed DG units is also optimized when considering economic dispatch of the classical problem [5].

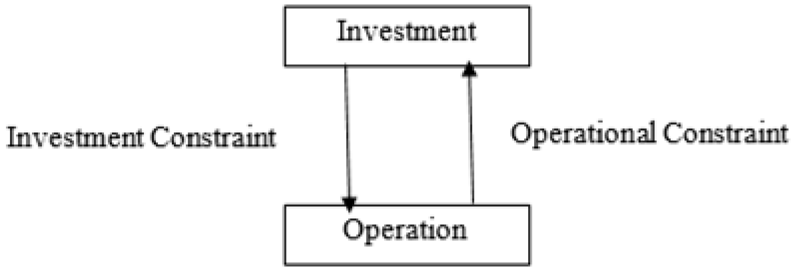

Figure 1: Relationship between Operational Decision and Investment Decision [5].

Micro grids are systems that have Distributed Energy Resources (DER) and associated load that can form international islands in distribution systems [16]. Distributed energy resources (DER), comprises distributed Generation (DG) and Distributed storage (DS), and is energy sources located close to the loads. This improves reliability if they are properly operated in the electrical distribution system. Loads and energy resources can be connected and reconnected within the local system with minimal disruption [16]. For proper working conditions of micro grids, an **upstream switch** must open especially during an unacceptable power quality and on **Islanded** section the DER must be able to carry the load. DER assigned to carry the island load should be able to restart and pick up the island load after switch has opened in island operational scenarios.

The components of a microgrid are shown in figure 2

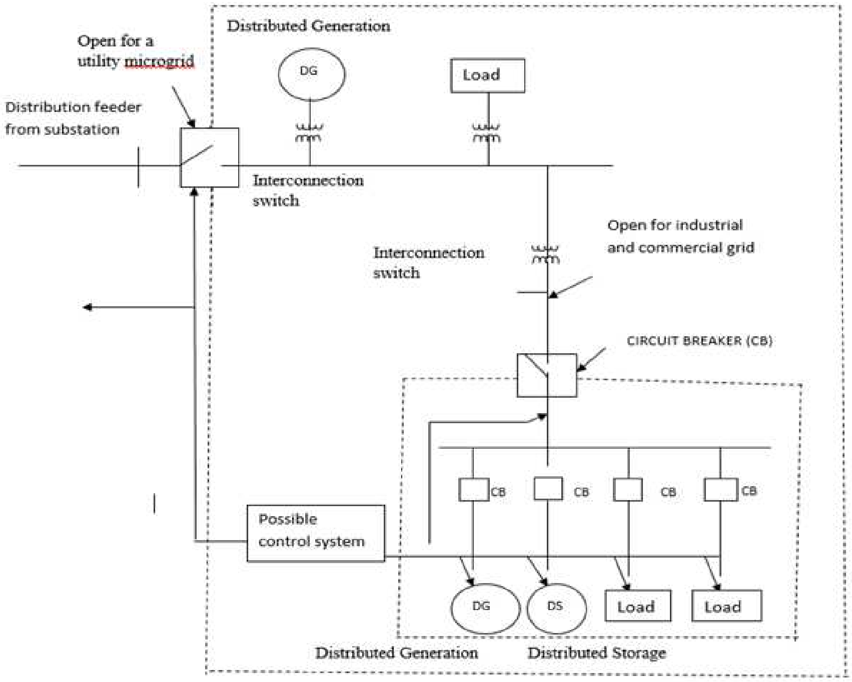

Figure 2: Micro Grids and Components: [16].

Micro Grids Technologies include: DG, DS, Inter-connection switch and control systems.

The authors in [6]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.Swathi and Simaria [7] deployed Ant Colony Search Algorithm (ACSA) Software or optimal siting and sizing of multiple DG to obtain power loss reduction from 0.224 MW loss to 0.083 MW loss. Similarly, in [8] 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 obtained revealed that technical losses have reduced from 0.06 MW to 0.03 MW (50% reduction) and 0.06 MW to 0.02 MW (67% reduction).

[9]Applied Genetic Algorithm for optimal DG siting, voltage profile improvement and loss reduction in distribution network system was effective. The method was programmed under MATLAB software and they used ETAP Application software for evaluating result correctly.[10]Proposed modified Bat Algorithm for power loss reduction in electrical distribution system tested on 33 bus system and the result show loss reduction rate of 33%.Also [11]showed that Genetic Optimization Algorithm for optimal placement and sizing of distributed generation units in residential distribution grid was effective.

Furthermore [12] Used Particle Swarm Optimization (PSO) techniques for Minimization of power loss and improvement of voltage profile by optimal placement of wind generator in distribution network.This technique was compared with heuristic method and Analytical method. In [13]the authors used 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 there was voltage level improvement. In related development [14]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. 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 [15]Applied modeling on a distribution network and Differential Evolution for Optimization. Assessment and physical investigation and analysis of an existing distribution network feeder was the primary target of their work whilst Genetic Algorithm was used to optimize DG siting, which resulted in 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.

MATERIAL AND METHOD

This thesis on enhanced optimal siting and sizing of DG on distribution network to minimize power losses and improve voltage profile will be considered using Electrical Transient Analysis Program (ETAP) version 12.6 software application package. 11kV Dikko feeder, Suleja distribution network, AEDC was modeled and simulated, optimal siting and sizing of DG has been actualized by Genetic Algorithm Optimization techniques.

Suleja Electricity Distribution Network

The Suleja Electricity Distribution network consists of 4 major injection substations 1 X 15MVA Field Base injection substation supplying 11kV Suleiman Barau and Tommy feeders, 2 X 15MVA Kantoma Injection substation supplying 11kV Dawaki and Hassan Dallatu feeders and 1 X 7.5MVA 132/11kV Suleja TS supplying 11kV Minna Road, Water Works, Dikko, NNPC feeders; 2 X 7.5 MVA Dikko Injection substation supplying 11kV Nasara feeder.

Data Collection

During the study of this project, 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 name plate, on- line, suppliers and contractors document.

Direct observation and telephone call techniques were also employed. Percentages loading on 11/0.415kV distribution transformers were collected from AEDC Suleja Office and unavailable ones were calculated using equations3.11, 3.12, and 3.13.

$$I_T=I_R+I_Y+I_B \quad (3.11)$$

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

$$P = \sqrt{3}VI \qquad (3.12)$$

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

$$Transformer\ \%\ loading = \frac{\left(\frac{R+Y+B}{3}\right)}{Transformer\ rating\ \sec\ (amps)} X\ 100 \qquad (3.13a)$$

Or

$$Transformer\ \%\ loading = \frac{Average\ load\ on\ 3\ phases}{KVA\ (amps)} X\ 100 \qquad (3.13b)$$

Objective Function

The objective function of this project work are to minimize the power losses and improve the voltage profiles across the line length of the distribution network.

Therefore, the objective function is expressed as follows

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

- Power losses reduction
- Improvement of voltage profiles
- $Losses_{withDG} \leq Losses_{withoutDG}$

$$Note: P_{loss} = I^2R \qquad (3.14a)$$

Where,

P_{loss} is the power loss

I is the line current

R is the line resistance

Apparent power from power triangle

$$S = |S| = V_{max}I_{max} = \sqrt{P^2 + Q^2}\ VA \qquad (3.14b)$$

$$I = \frac{S}{V}\ ;\ I^2 = \left(\frac{\sqrt{P^2 + Q^2}}{V}\right)^2 \qquad (3.14C)$$

$$\therefore I = \frac{P_i^2 + Q_i^2}{V_i^2} \qquad (3.15)$$

Where,

P_i is the active power losses;

Q_i is the reactive power losses;

V_i is the bus voltage

$$f = maxLLR\% = \frac{LL_{WODG} - LL_{WDG}}{LL_{WODG}} X\ 100 \quad [45] \qquad (3.16)$$

Where,

$$LL_{WDG} = \sum_{l=1}^{N} I_{l,W_{DG}}^{2} R_l D_l \qquad (3.17)$$

$$LL_{WODG} = \sum_{l=1}^{N} I_{l,WO_{DG}}^{2} R_l D_l \qquad (3.18)$$

- *f* is the objective function
- LLR% is the percentage reduction of the line loss due to DG;
- LL_{WDG} is the line loss with DG, pu;
- LL_{WODG} 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;
- $I_{l,WDG}$ is current value of line l in pu after DG installation;
- $I_{l,WODG}$ is the current value of line l in pu before DG installation. [45]

(a) Voltage deviation

$$VD_i = |1 - V_i| \qquad (3.19)$$

Sum of voltage deviations

$$SVD_i = \sum_{i=1}^{n} |1 - V_i| \qquad (3.20)$$

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

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

The following constraints were considered using genetic algorithm optimization:

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.

- **Power Injection Constraints;**

$$\sum_{i=l}^{n} P_{DG} < P_{load} + P_{losses} \qquad (3.21)$$

- **Total Power Balanced Constraint**

$$\sum_{i=1}^{n} P_{DG} + P_{substation} = P_{load} + P_{losses} \quad (3.22)$$

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

- **Total number of DG**

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

$$N_{DG} \leq N_{DG/MAX} \quad (3.23)$$

- **DG generation capacity constraint**

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

$$P_{ga}^{min} \leq P_{ga} \leq P_{ga}^{max} \quad (3.24)$$

- **Voltage and current constraint**

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

$$V_{min} \leq |V_i| \leq V_{max} \quad (3.25)$$

$$|I_j| \leq I_{max} \quad (3.26)$$

Where,

$|V_i|$ is the voltage magnitude of node I,

V_{min}, V_{max} is the minimum and maximum voltage limits, respectively

$|I_j|$ is the current magnitude of each line j,

I_{jmax} is the maximum current limit of line j [45]

Coding for DG Installation

In correct implementation of the GA and to achieve the best results, coding of the solution is necessary.

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) represents 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) represent the active power of DGs and the second 4 bits (6th to 9th) represent the reactive power of DGs. [45].

This is shown in figure3.

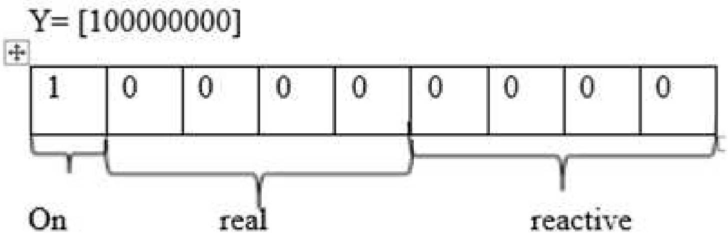

Figure 3.1: Illustrates Chromosome of a Generator Working at Minimum Capacity (on).

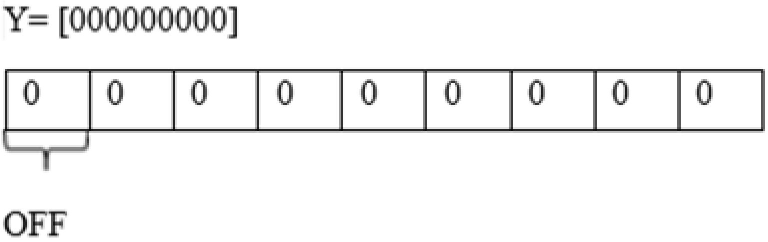

Figure 3.2: Illustrates Chromosome of a Generator Not Existing or Not Operating (Off).

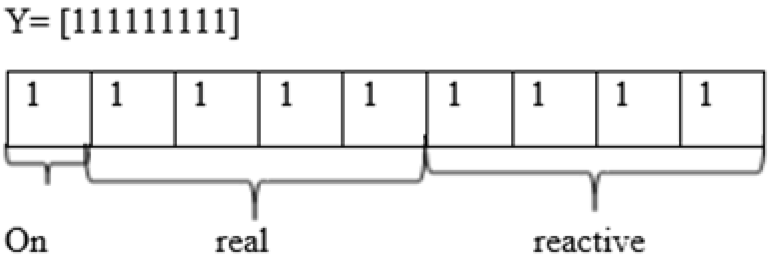

Figure 3.3: Illustrates Chromosome of a Generator Working at Full Capacity (On).

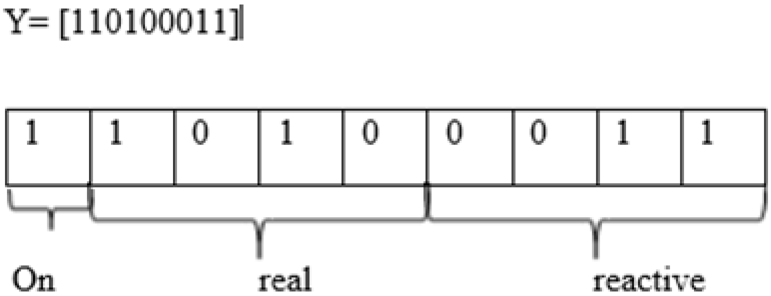

Figure 3.4: Illustrates Chromosome of a Generator Working at Active Power Capacity of 33.33% and Reactive Power Capacity of 80%,When Considering Fixed Weight of 8421.[45].

DG Placement

Each string Y is a representation of generator size to be placed at a given node. This placement location representation is straight forward 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 figure 3.5 below.

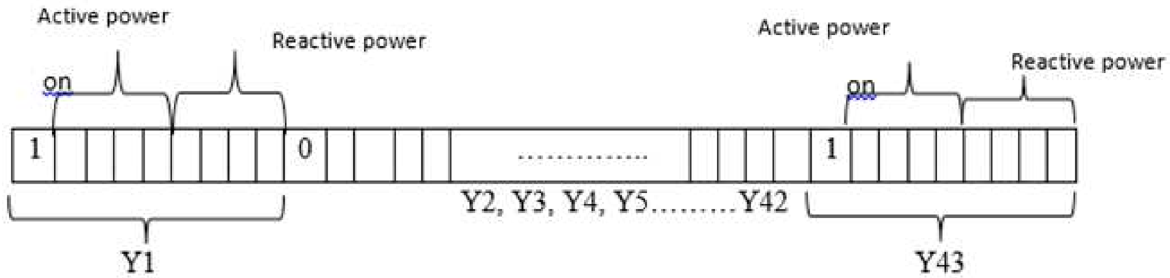

Figure 3.5: Showing Chromosome Z. [45].

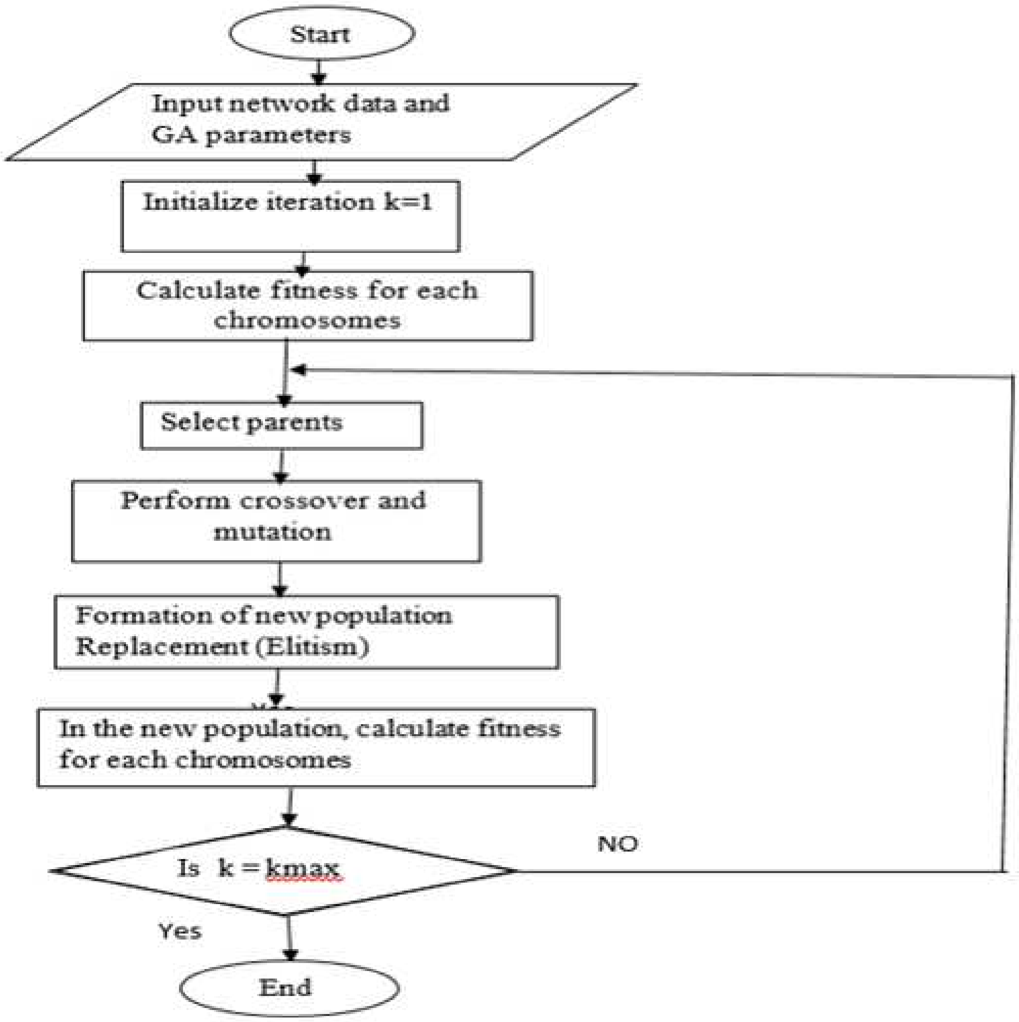

Figure 3.6: GAO Flowchart for Optimal DG Siting and Sizing. [36].

Network Modeling 11KV Dikko Feeder

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 [46] with all data collected and input for the analysis of the network.

Computation of the Transformer ratings, voltage ratio (11/0.415kV) and impedances for all distribution transformers were done in ETAP [46] environment coupled with the other technical information required which are embedded in the software library were also selected. 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 3.7 shows the Dikko feeder modeled in ETAP.

One- Line Diagram - OLV1 (Edit Mode)

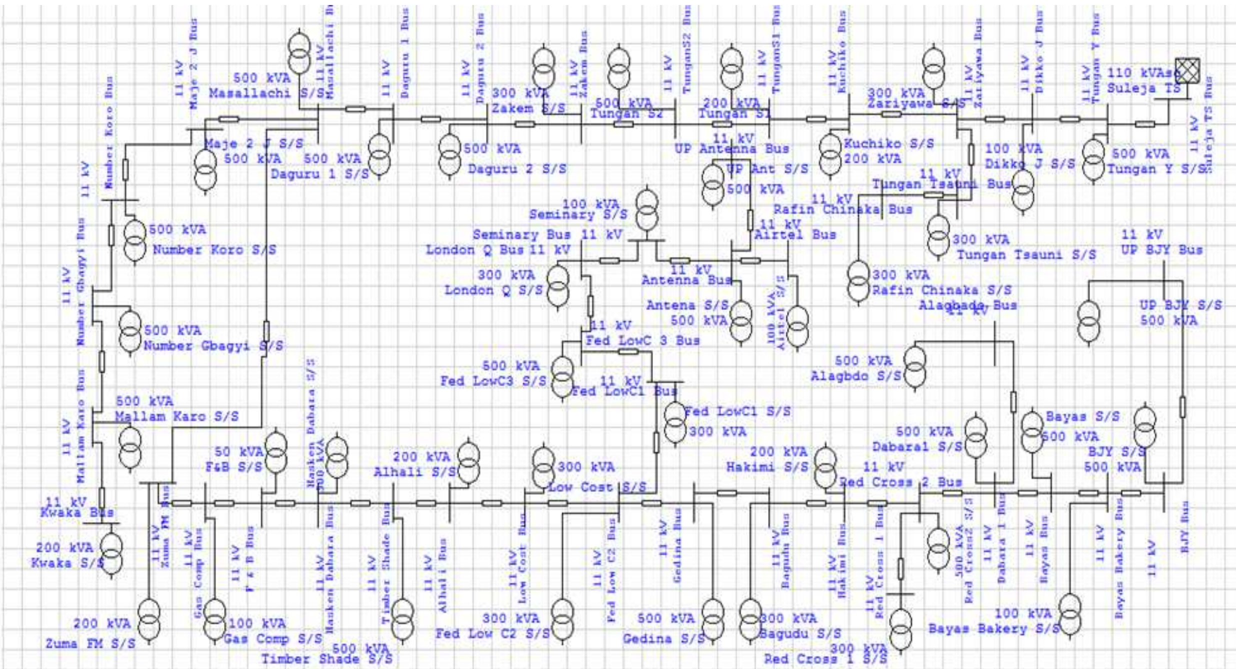

Figure 3.7: Single Line Diagram of the Dikko Feeder Modeled in ETAP.

Deployment of Genetic Algorithm

The Genetic Algorithm Optimization (GAO) was implemented in MATLAB software to determine optimal location for DG installation. The GAO deployment was to actualize and properly identify the points for DG placement. The buses considered best for the location of DG at the end of optimization were buses 1, 12, 25 and 41.

Simulation of Distributed Generator on the 11KV Dikko Feeder

Simulation with Distributed Generation in place were implemented on 11KV Dikko feeder, results were obtained. Bus number 12 was considered the best optimal point for DG placement from the GAO optimization result with highest active and lowest reactive power. However, buses 1, 25, and 41 were also considered for an effective result on the modeled network.

- Figure 3.8 shows ETAP model of 11kV Dikko Feeder with DG connected
- Figure 3.9 shows Load Flow Display model of 11kV Dikko Feeder with DG connected

One- Line Diagram - OLV1(Edit Mode)

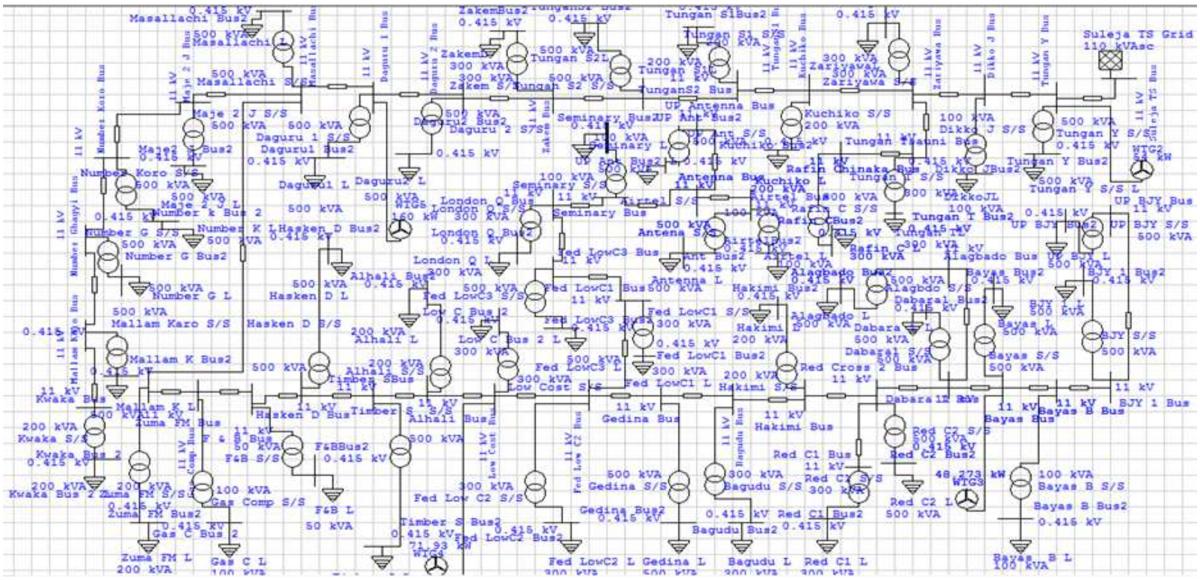

Figure 3.8: ETAP Model of 11kV Dikko Feeder with DG Connected.

One- Line Diagram- OLV1- Edit Mode (Load Flow Analysis)

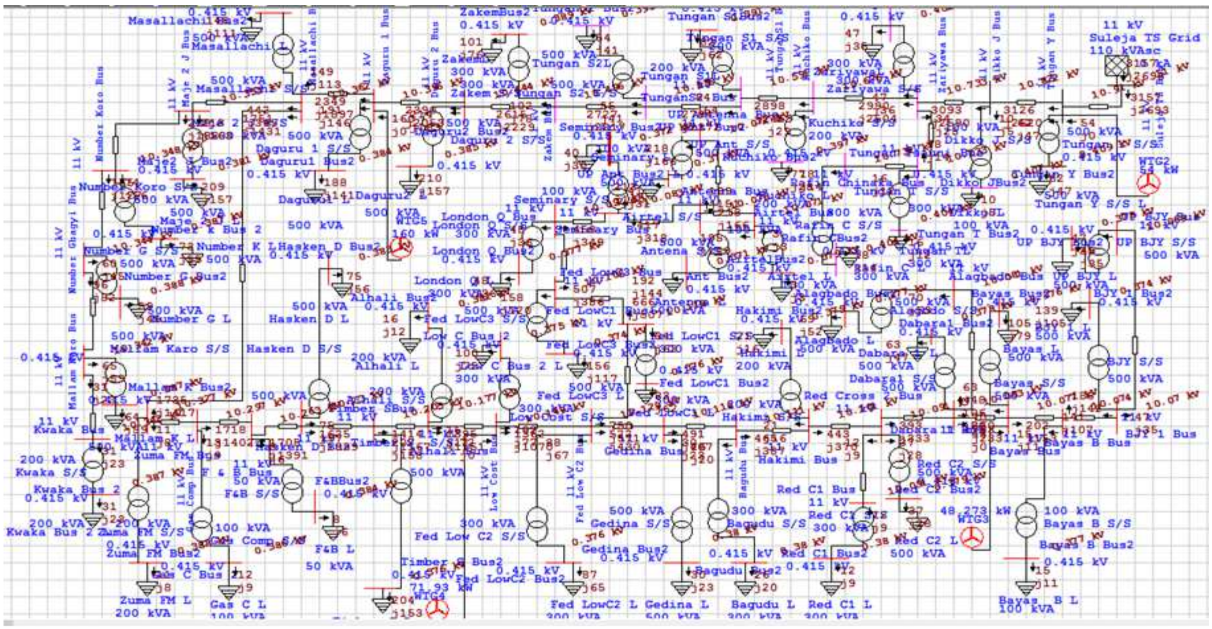

Figure 3.9: Load Flow Display Model, 11kV Dikko Feeder with DG Connected.

RESULTS 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 system by installing DG at best locations.

ETAP Interface

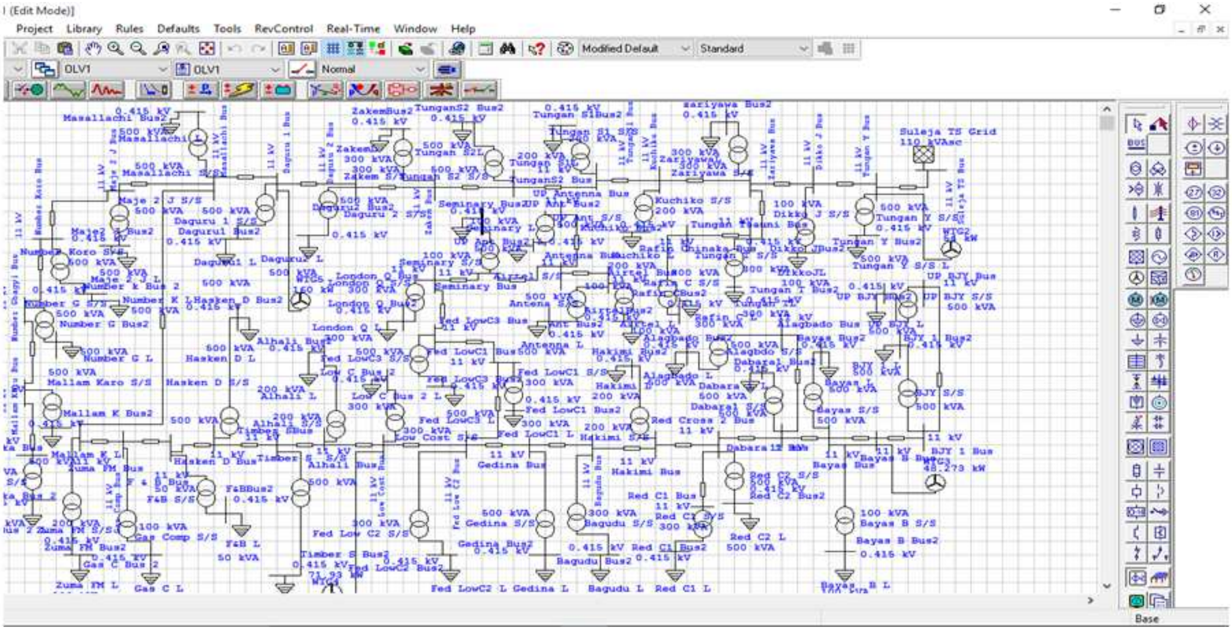

Figure 4.1: Shows ETAP Interface.

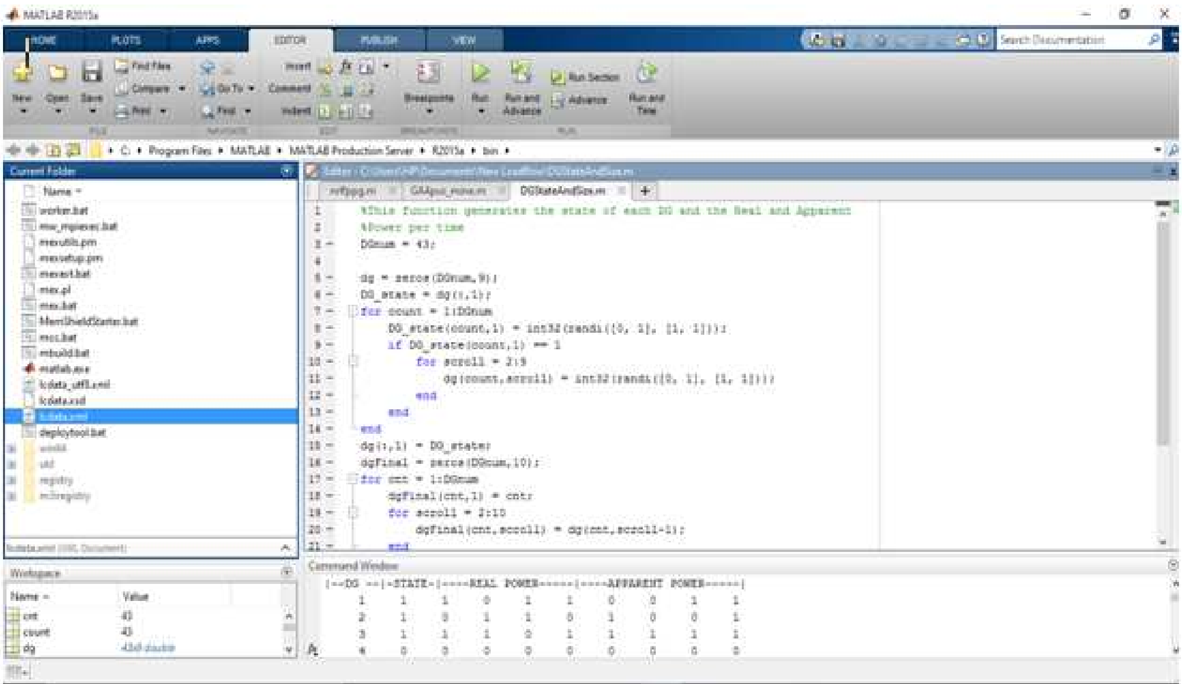

Figure 4.2: Shows Matlab Interface.

Results

Table 4.1 illustrates summary of results obtained from Load Flow Analysis carried out on Dikko Feeder without DG connection to the network.

Table 4.1: Load Flow Result Summary of Dikko Feeder without Distributed Generator

Active Power Losses (kW)	Reactive Power Losses (kVar)
246.300	289.903

Table 4.2 shows summary of results obtained from Load Flow Analysis carried out On Dikko Feeder with DG connection to the network.

Table 4.2: Load Flow Result Summary of Dikko Feeder with Distributed Generator

Active Power Losses (kW)	Reactive Power Losses (kVar)
226.356	267.040

Table 4.3 shows summary of results obtained from Load Flow Analysis carried out onDikko Feeder with and without DG connection to the network.

Table 4.3: Comparison of Load Flow Results Summaries Along 11kV Dikko Feeder both With and Without Distributed Generator. i.e. Table 4.1 and 4.2

Without Distributed Generator		With Distributed Generator	
Active Power Losses (kW)	Reactive Power Losses (kVar)	Active Power Losses (kW)	Reactive Power Losses (kVar)
246.300	289.903	226.356	267.040

Table 4.4 shows result of power losses reduction for DG optimal placement Type 4 in the 43Bus system.

Table 4.4: Results of Power Losses Reduction for DG Optimal Placement

Method	Bus No	DG size (kW)	DG size (kVar)	Active Power Losses (kW)	Reactive Power Losses (kVar)	%Loss reduction Active	%Loss reduction Reactive
Load flow Analysis				246.300	289.903		
GA	1	54.00	37.37				
	12	160.33	18.53	226.356	267.040	8.10	7.20
	25	71.93	33.44				
4148.27	32.92						

Table 4.5 shows the summaries of Active and Reactive Power losses on the lines with and without DG on Dikko Feeder.

Table 4.5 Summaries of Active and Reactive Power Losses on Dikko Feeder With and Without DG Installations

Losses Without DG		Losses With DG	
Active Power Losses (kW)	Reactive Power Losses (kVAR)	Active Power Losses (kW)	Reactive Power Losses (kVAR)
206.363	229.680	186.156	206.430

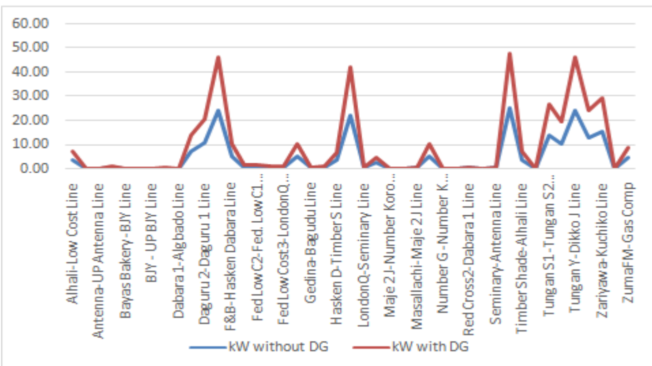

Figure 4.3: Active Power Losses on Dikko Feeder With and Without DG.

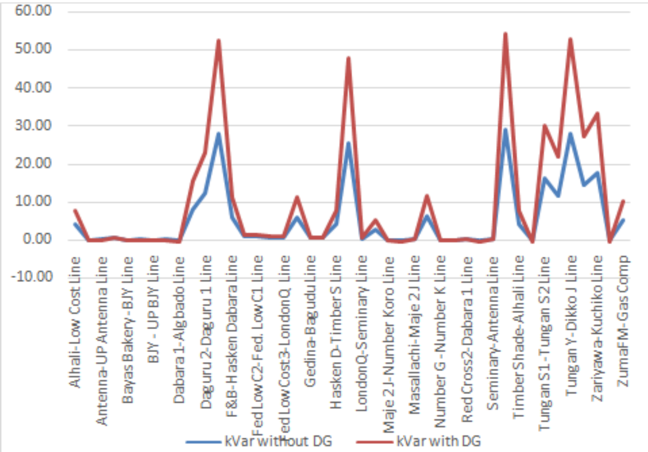

Figure 4.4: Reactive Power Losses on Dikko Feeder With and Without DG.

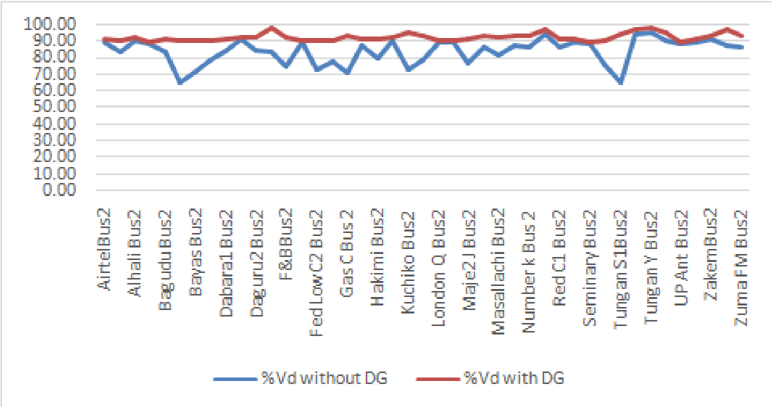

Figure 4.5: Voltage drops on Dikko Feeder With and Without DG.

Figure 4.6: Bar Chart Representing Active and Reactive Power Losses.

Discussion of Results

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 3.7. The data of the system were obtained from AEDC, Suleja. The total load of the system was considered to be (3490 + j2700) kVA and total active and reactive power losses in the system before DG installation were 246.300 kW and 289.903 kVAR respectively as shown in Table 4.1.

Optimum size and location of DGs in Type 4 for minimization and percentage loss reduction of losses were determined and shown in table 4.4. Also 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 considerable effects on loss reduction in the network. It is observed that 8.10% and 7.20% active and reactive loss reduction results from this process.

Reduction in active and reactive power loss on lines with and without DG were 9.80% and 10.12% respectively. These are represented with curves on Figures 4.1 and 4.2

Table 5.5: Appendix B shows the comparison in percentage voltage drop of Dikko feeder with and without DG BJY – Up BJY line and Tungan S1 Bus 2 have the poorest voltage profile without DG on the network, having voltage drop of 9.63%. This bus voltage improved to 0.4% drop when DGs were installed on the feeder, with an improvement of 9.23%. This improvement has an impact on other buses in the network as all voltages drop below the acceptable limit of ±6%. This is represented in the graph shown in Figure 4.3.

Power Losses Reduction

Table 4.2 shows the result of Load Flow analysis obtained when DGs were installed and simulation was carried out on Dikko Feeder. Genetic Algorithm Optimization result obtained was used to fast track and guide the choice of DGs optimal placement in the network bus. Reduction of total active and reactive power losses from (246.300kW, 289.903kVAR) to (226.356kW, 267.040 kVAR) respectively were achieved. These represent about 8.10% and 7.20 reductions respectively.

Voltage Improvement

It is observed that the percentage voltage losses before DG installation were more than those recorded after DG installation.

Over85% of buses were observed to have more than 6% permissible limit of voltage drop when the load flow analysis was carried out on Dikko Feeder without DG installation. However, more of the buses had voltage drop above 4% after the DG installations and simulation on the same feeder. Hence, a considerable effect onimprovement of voltage profile was achieved.

CONCLUSIONS

The aim of this research is 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. It is also to identify buses with poor voltage profile in the distribution network without DG installations and it was discovered that percentage voltage drop on Dikko feeder, BJY – Up BJY line and Tungan S1 Bus 2 have the poorest voltage profile with drop of 9.63%.This bus voltage drop improved to 0.4% when DGs were installed on the feeder.

On the determination of optimal sizing and siting of DGs where losses can be mitigated and power quality improved we were able to achieve DG size of 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 enhanced work achieved reduction of total active and reactive power losses from (246.300kW, 289.903k VAR) to (226.356kW, 267.040 kVAR) respectively. This represent about 8.10% and 7.20 reductions respectively.

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