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Optimal Deployment of Distributed Generators using Ant Colony Optimization to Minimize Line Losses and Improve Voltage Profiles on Distribution Network

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***Abstract*- Power losses and poor voltage profiles are becoming common problems in some part of Nigeria distribution network owing to its large and complex system which has been addressed partly by this study. This paper focuses on the optimal placement of Distributed Generator (DG) on distribution network to minimize power losses and improve voltage profile. An 11 kV Piggery distribution feeder of Abuja Electricity distribution Company, Minna was modelled in Electrical Transient Analysis Program (ETAP). Subsequently, load flow analysis of the network was carried out to establish a base case by simulation. Ant Colony Optimization (ACO) program written in MATLAB was used for the optimal placement of DG on the system. The results obtained showed 10.7% improvement in the voltage profile of the system and 66% percent reduction in power line losses.**

***Index Terms*- Distributed Generation, Voltage Profile, ETAP, Ant Colony Optimization, MATLAB, Power losses.**

I. Introduction

Electrical energy is almost an indispensable form of energy for socio-economic growth and development of any country. Over the last decade, Nigerian electrical power system has been facing enormous challenge, from generation to distribution. Its reliability is being threatened regularly. The end delivery to consumers largely rests on the happenings between generating stations and distribution substations. Distribution networks are mostly characterized with high power line losses due to higher value of R/X. Consequently, low voltages are experienced in many places in Nigeria especially those consumers that are remotely located or are connected to distribution network at fairly far away distance from their service transformers. In Nigeria, electricity distribution is at 230V for single phase and 415 V for three phase connections.

Quiet a large number of customers have less than 180 V due to enormous losses along the distribution lines, especially those located at extremely far away from distribution transformer serving them.

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These undesirable effects of losses and poor voltages on distribution network could be well mitigated by adequate deployment of Distributed Generator at an optimal location(s) in the distribution network. Optimization is a process by which we try to find out the best solution from set of available alternatives. In DG allocation problem, DG locations must be optimized in such a way that it gives most economical, efficient, technically sound distribution system. In order to achieve optimal point on the distribution network, artificial intelligence technique that was employed for the purpose of DG placement is the Ant Colony Optimization Technique. An 11 kV distribution feeder from Abuja Electricity Distribution Company, Minna network was considered for a case study to establish the current line losses and subsequent effects DG has on it after installation by simulation on ETAP software package.

II. LITERATURE REVIEW

A number of researchers have worked on distribution network to minimize power losses, among them are [7], who adopted Clonal algorithm method, a population based meta heuristic approach was used for the DG placement in a radial distribution systems, and the results showed that a significant reduction in power losses from 222 kW loss to 116.6 kW for a unit DG and 45.5 kW for 2 unit DG installation on the network were recorded. Also, [8] showed that Genetic Algorithms (GA) for optimal DG placement, voltage profile improvement and loss reduction in distribution network was effective. The method was programmed under MATLAB software and they applied ETAP software for evaluating results correctness. GA gives nearly optimal results but are computational demand and slow in convergence. Similarly, a combination of fuzzy interface and analytical approach was implemented to achieve an effective reduction in the real power losses by 57% and improved the voltage profile in radial distribution network [9]. This work did not optimize DG placement though loss reduction was achieved, optimisation approach method could have given better result if adopted.

In the work of [10], optimal location of DG on a radial feeder was used to minimize power loss, Analytical and non iterative algorithms methods were adopted and at the end of their work, 75% loss reduction was achieved. The method required complex mathematical expression based on phasor current to solve location problem. In this work, Ant Colony was used as optimization tools for its better convergence and less mathematical demand for DG placement and ETAP as the software for modelling and simulation.

A. Definition of Distributed Generation

There is no globally accepted definition of DG, this is due to variations in the definition terms like the purpose, location, technology, mode of operation, rating, power delivery area and penetration. Definition based on DG location will be considered in this work. The location of distributed generation is defined as the installation and operation of electric power generation units connected directly to the distribution network or connected to the customer side of the meter [2].

Distributed generation (DG) devices can be strategically placed in a power system for grid reinforcement, reducing power losses and on-peak operating costs, improving voltage profiles and load factors, deferring or eliminating system upgrades, and improving system integrity, reliability, and efficiency [11].

B. Classifications of Distributed Generation

The DG technologies are classified into two categories: (i) Renewable Energy Sources (RES) and (ii) Fossil fuel-based sources. Renewable energy source (RES) based DGs are wind turbines, photovoltaic, biomass, geothermal, small hydro, etc. Fossil fuel based DGs are the internal combustion engines (IC), combustion turbines and fuel cells. These distributed generators needed to be connected in distribution systems in such a manner that it avoids degradation of power quality and reliability.

III. ANT COLONY OPTIMIZATION

In the natural world, ants wander randomly searching for food, and upon finding food, return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random again, but follow the trail, returning and reinforcing it if they eventually find food (see Figure 1).

Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones. Pheromone evaporation also has the advantage of avoiding the convergence to a locally optimal solution. If there were no evaporation at all, the paths chosen by the first ants would tend to be excessively attractive to the following ones. In that case, the exploration of the solution space would be constrained. These ants behaviour has been used to develop mechanism to solve most complex combinatorial problems, same also adopted to solve DG placement in this work.

A. Network, Software and Data Collection

The studied distribution network is a 33/11 kV substation taken from Abuja Electricity Distribution Company (AEDC) having a 15 MVA Power Transformer installed at the Power House Substation and supplied consumers via 60 numbers of 11/0.415 kV installed distribution transformers in various locations within Minna township.

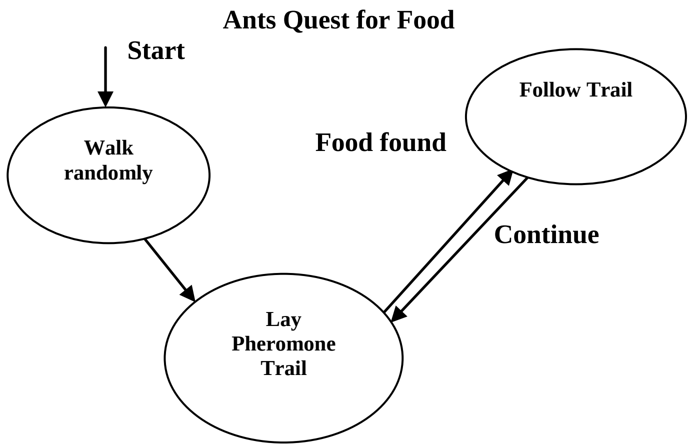

Fig 1: Ants search techniques

Electrical Transient Analysis Program (ETAP) version 12.6 software packages was used in modelling and simulation of the network under study and optimal placement of DG on this distribution feeder was realized by ant colony optimization techniques.

Distribution Transformers Phase Current readings were taken from AEDC office, total three phase current and transformer loadings were calculated using equations 1 and 2. Table 1 shows Piggery Feeder information used for network analysis.

Total Current $I_{TL} = I_r + I_b + I_y$ (1)

Where I_r is current on the red phase

I_b is current on the blue phase

I_y is current on the yellow phase

Transformer Loading, $kVA = \dfrac{\sqrt{3} \times volts \times amps}{1000}$ (2)

B. Objective functions

The objective function in this work is to minimize power loss and improve voltage profile across the distribution line. These would be achieved by the following equations.

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

1. Power losses reduction

$$Losses_{with\ DG} \leq Losses_{without\ DG}$$

$$f = P_{loss} = \sum_{i=1}^{n} R_i \frac{P_i^2 + Q_i^2}{v_i^2} \quad (3)$$

where P_i = is the active power losses

Q_i = is the reactive power losses

V_i = line voltage

R_i = line resistance

n = is the total number of buses in the network

2. Improvement of voltage profiles.

Voltage deviations

$$VD_i = |1 - V_i| \quad (4)$$

Sum of voltage deviations

$$SVD_i = \sum_{i=1}^{n} |1 - V_i| \quad (5)$$

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

Considering ($0.95 \leq V_i \leq 1.05$) for voltage deviations of ±5%, being acceptable limit.

The objective function with constraints are given as follows, thus, losses before DG installation in the feeder should be less than losses after installation of DG to the feeder.

$$MaxF = \left\{ \max\left(0, \frac{1}{n}\sum_{i=1}^{n}(Voltage\%_{iwDG} - voltage\%_{iwtDG})\right)\right\} + \left\{\max\left(0, \sum_{j=1}^{m}(P_{jwtDG} - P_{jwDG})\right)\right\} + \left\{\max\left(0, \sum_{j=1}^{m}(Q_{jwtDG} - Q_{jwDG})\right)\right\} \quad (6)$$

where, $Voltage\%_{iwDG}$ is the percentage voltage in i^{th} bus with DG installed, $Voltage\%_{iwtDG}$ is the percentage voltage in i^{th} bus without DG installed, P_{jwDG} is the Active Power Losses in branch j^{th} with DG installed, P_{jwtDG} is the Active Power Losses in branch j^{th} without DG installed, Q_{jwDG} is the Reactive Power Losses in branch j^{th} with DG installed, Q_{jwtDG} is the Reactive Power Losses in branch j^{th} without DG installed, n is the number of buses, m is the number of branches, j^{th} is the number of branches.

C. Distributed Generator Optimization Constraints

To have a steady state system, the active power supplies to the network should be prevented from flowing back to the substation, this will avoid occurrence of undesired and unnecessary faults in the systems.

Power Injection Constraints:

$$\sum_{i=1}^{k} P_{DG} < P_{load} + P_{losses} \quad (7)$$

Total Power Balanced Constraint:

$$\sum_{i=1}^{k} P_{DG} + P_{substation} = P_{load} + P_{losses} \quad (8)$$

where,

P_{DG} = Power supply by DG

$P_{substation}$ = Power supply from substation

P_{load} = Power delivered to the network connected loads

P_{losses} = Power losses on the network

k = Number of distributed generator connected

Voltage constraint:

$$V_{min} \leq V_{bus} \leq V_{max} \quad (9)$$

Voltages at all points should be within the acceptable limits of ±5% of voltage values.

The total power loss in a distribution system having 'n' number of branches is given by

$$P_{TL} = \sum_{i=1}^{n} I_i^2 R_i \quad (10)$$

where

I_i = the current magnitude

R_i = the resistance

The current has two components, active component and reactive component, which can be written as [9],

$$P_{TL} = P_{La} + P_{Lr} \quad (11)$$

$$P_{TL} = \sum_{i=1}^{n} I_{ai}^2 R_i + \sum_{i=1}^{n} I_{ri}^2 R_i \quad (12)$$

IV. Modelling and Simulation of the Piggery Feeder

Piggery feeder is modelled in ETAP (Version 12.6) using data in Table 1 to run the Load flow analysis. Transformers ratings, impedances and voltage ratio (11/0.415 kV) of all distribution transformers in the network are computed in ETAP environment, while other technical information required were selected from the software embedded library.

The length of distribution lines shows the distance between any two transformers in the network; this is again used in the network modelling as required by the ETAP application. ACSR conductor was selected as being the conductor type used in 11 kV distribution reticulations in the network. All cable specifications needed for conductor modelling were chosen from ETAP in-built conductor library. The cable used for 11 kV down droppers was 11 kV XLPE, the technical detailed of this was also contained in ETAP cable library.

A. Deployment of Ant Colony Optimization (ACO)

The Ant Colony Optimization was implemented in MATLAB environment to determine optimal point for DG installation. The ACO was deployed to identify appropriately the location(s) for DG placement. Buses considered best for the location of DG at the end of optimization were buses 126 and 129. Table I shows the DG placement results on buses 126 and 129.

TABLE I

COMPARISON OF RESULTS OF POWER LOSSES FOR DG PLACEMENT ON BUSES 126 AND 129

S/No	DG Placement Bus No	Bus No	Active Power losses (kW)	Reactive Power losses (kVar)
1	DG	126	173.5	197.7
2	DG	129	150.4	175.8

B. Simulation of Distributed Generator on the Piggery Feeder

Simulations with Distributed Generator in place were implemented on piggery feeder, and results were obtained.

However, bus 126 was the best optimal point for DG placement from the ACO optimization result, it was the bus

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that gave lowest active and reactive power loss on the modelled network. Tables II and III show results obtained from Piggery feeder with DG connected by ETAP.

V. RESULTS

TABLE II
SUMMARIES OF ACTIVE AND REACTIVE POWER LOSSES WITH AND WITHOUT DG ON THE PIGGERY FEEDER.

	CKT / Branch	Losses Without DG		Losses With DG	
S S/No	ID	kW	kVar	kW	kVar
1	Line1	59.2	34.6	3.7	2.0
2	Line2	68.2	39.9	4.1	2.2
3	Line3	35.5	20.8	1.5	0.8
4	Line4	17.1	10.0	0.7	0.3
5	Line5	32.3	18.9	1.0	0.5
6	Line6	16.0	9.4	0.5	0.2
7	Line7	24.0	14.0	0.7	0.3
8	Line8	1.5	0.8	1.7	0.9
10	Line9	1.2	0.6	1.4	0.7
11	Line10	1.0	0.5	1.1	0.6
12	Line11	0.2	-0.1	0.2	0.0
13	Line12	0.1	0.0	0.1	0.0
14	Line13	21.0	12.3	0.3	0.1
15	Line14	0.2	-0.1	0.1	-0.1
16	Line15	1.3	0.7	1.5	0.8
17	Line16	0.6	0.3	0.7	0.3
18	Line17	0.3	0.1	0.4	0.2
19	Line18	0.4	0.2	0.4	0.2
20	Line19	0.1	-0.1	0.1	0.0
21	Line20	0.2	-0.1	0.2	0.0
22	Line21	0.2	0.0	0.2	0.0
23	Line22	0.2	-0.1	0.3	0.0
24	Line23	0.1	-0.1	0.1	-0.1
25	Line24	0.1	0.0	0.1	0.0
26	Line25	0.2	-0.1	0.1	-0.1
27	Line26	0.0	0.0	0.1	-0.1
28	Line27	0.0	-0.1	0.0	-0.1
29	Line28	0.2	-0.1	0.1	-0.1
30	Line29	11.8	6.8	2.5	1.4
31	Line30	8.6	5.0	2.0	1.1
32	Line31	5.3	3.1	1.6	0.9
33	Line32	5.0	2.9	1.8	1.0
34	Line33	4.7	2.7	2.0	1.1
35	Line34	4.5	2.6	2.1	1.2
36	Line35	4.4	2.6	2.1	1.2
37	Line36	3.7	2.2	2.7	1.6
38	Line37	5.3	3.0	4.4	2.5
39	Line38	6.1	3.5	6.9	4.0
40	Line39	2.7	1.6	3.8	2.2
41	Line40	0.1	0.0	0.2	0.0
42	Line41	1.8	1.0	5.4	3.1
43	Line42	0.6	0.2	0.7	0.3
44	Line43	0.2	0.0	0.2	0.0
45	Line44	0.1	0.0	0.1	0.0
46	Line45	0.1	-0.1	0.0	0.0
47	Line46	0.1	-0.1	0.0	0.0
48	Line47	0.1	-0.1	0.1	0.0
49	Line48	0.2	0.1	0.1	0.0
50	Line49	0.8	0.4	1.0	0.5
51	Line50	0.9	0.5	1.2	0.6
52	Line51	0.4	0.2	0.5	0.2
53	Line52	0.7	0.0	0.2	0.1
54	Line53	0.2	0.0	0.1	0.0
55	Line54	0.2	0.0	0.2	0.0
		349.9	**200.2**	**63.0**	**32.3**

TABLE III
SUMMARIES OF PERCENTAGE VOLTAGE DROP ON PIGGERY FEEDER WITH AND WITHOUT DG

S/No	Bus No	%Vd without DG	%Vd with DG
1	Bus3	95.9	98.8
2	Bus6	94.6	98.5
3	Bus9	94.0	98.4
4	Bus14	93.6	98.3
5	Bus15	93.0	98.2
6	Bus20	92.7	98.2
7	Bus23	92.2	98.1
8	Bus26	92.0	98.0
9	Bus29	91.7	98.2
10	Bus32	91.6	97.5
11	Bus33	91.3	97.2
12	Bus38	91.6	97.5
13	Bus41	91.7	97.6
14	Bus44	91.8	97.6
15	Bus47	89.1	94.8
16	Bus50	91.7	98.2
17	Bus53	91.6	98.0
18	Bus56	88.9	95.2
19	Bus59	89.4	95.7
20	Bus62	90.7	97.1
21	Bus65	89.9	96.3
22	Bus68	88.8	95.1
23	Bus71	90.2	96.6
24	Bus74	90.1	95.9
25	Bus77	90.2	96.0
26	Bus80	90.9	96.7
27	Bus83	90.9	96.7
28	Bus86	89.6	95.4

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29	Bus89	91.1	97.0
30	Bus92	89.8	95.5
31	Bus95	89.8	96.7
32	Bus98	89.2	96.5
33	Bus99	89.1	96.7
34	Bus104	90.5	98.8
35	Bus105	88.0	96.1
36	Bus110	90.2	99.0
37	Bus113	87.9	96.5
38	Bus116	89.3	98.3
39	Bus121	88.1	97.5
40	Bus124	89.0	99.1
41	Bus126	89.4	99.8
42	Bus129	89.3	100.0
43	Bus130	88.2	98.5
44	Bus133	89.2	99.9
45	Bus136	87.4	97.9
46	Bus141	89.1	99.8
47	Bus144	86.3	96.6
48	Bus147	87.0	97.5
49	Bus150	89.4	99.8
50	Bus153	89.1	99.5
51	Bus156	87.7	98.2
52	Bus159	89.0	99.7
53	Bus162	87.9	98.5
54	Bus169	88.5	99.1

VI. Discussion of Results

The choice of DG optimal connection to the network bus was guided by the deployment of Ant Colony Optimization result obtained. A total reduction of active and reactive power losses to 73.1 kW and 82.8 kVar were recorded as against their initial respective values of 327.2 kW and 225.8 kVar when DG was not connected (see Figures 2 and 3). Over ninety percent of buses had more than 6% acceptable voltage drop when the Load flow was carried out on the Piggery Feeder without DG Installation, whereas, none of the buses have voltage drop exceeding 3% when the Load flow Analysis was carried after DG was connected by simulation of the entire network (see Figure 4). Hence, the total voltage drop after simulation shows significant improvement of 10.7% in the voltage profile of the network on the worse feeder.

VII. Conclusion

This paper has established that the optimal placement of DG on 11 kV distribution network could be deployed to minimize power losses in the system and improve voltage profile using ACO method whilst reliability of distribution network is greatly enhanced.

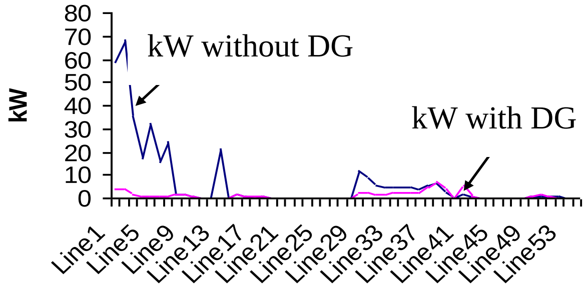

Fig. 2 Active power losses with and without DG on Piggery network

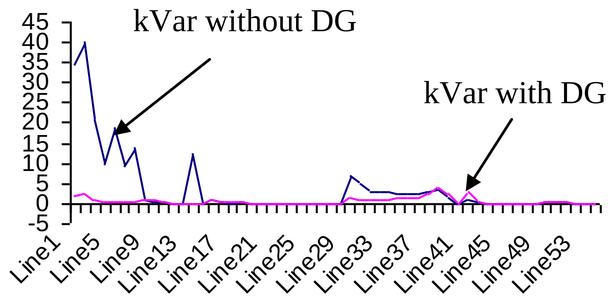

Fig. 3 Reactive power losses with and without DG on Piggery network

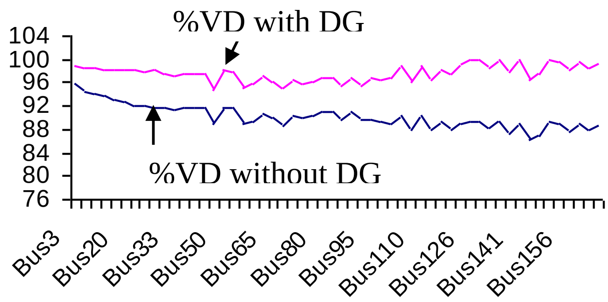

Fig. 4 Voltage drop with and without DG on Piggery network.

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