Optimum Sizing And Placement Of Distributed Generation Using Ant Colony Optimization Approach

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***Abstract*— In this paper, optimum sizing and placement of distributed generation using ant colony optimization approach is presented. The ACO mathematical model development is presented along with the flow diagram used for the implementation of the ACO on a case study 11 kV feeder line in Uyo Akwa Ibom State Nigeria. The bus dataset of the 11 kV feeder showed total active power of 15930 kW along with total reactive power of 7715.29 kVar. Under the condition of no distributed generation (DG), the feeder has about 13.23716259 % of active power loss and 10.06491007 % of reactive power loss. The ACO sizing and optimal placement of DGs on the 11 kV feeder were simulated with 30% DG penetration and the results showed that the total real power loss decreased from 2108.68 kW in the base case to 1050 kW when the DG is 1, 998 kW when the DG is 2 and 996 kW when the DG is 3. Similarly, the total reactive power loss reduced from 776.537 kVar to 387 kVar when the DG is 1, 368 kVar when the DG is 2 and 367 kVar when the DG is 3. Accordingly, with the implementation of the ACO algorithm, the real power was reduce by 50.21% when the DG is 1 to 52.06% when the DG is 2 and 52.76% when the DG is3. Again, with the implementation of the ACO algorithm, the reactive power was reduce by 50.16% when the DG is 1 to 52.10% when the DG is 2 and 52.73% when the DG is 3. In all, ACO can be effectively be used in the optimum sizing and placement of DGs in the power distribution networks.**

***Keywords*— Distributed Generation, Ant Colony Optimization, Optimum Sizing Of Distributed Generation, Voltage Deviation Index, Optimal Placement of Distributed Generation**

1. INTRODUCTION

The integration of DG into radial power distribution systems has been identified as a promising solution that enables the power grids to meet the ever-increasing demand of electricity while increasing the reliability and cost efficacy of power grids [1,2,3]. To maximise the benefits, optimal sizing and placement of DG units must be determined [4,5]. Specifically, the appropriate sizing and placement of DG units play an important role in reducing power losses and maintaining voltage stability of the power grid [5,6,7]. On the other hand, if the sizing and placement of the DG units are not determined appropriately, it can increase power losses, voltage instability, and even lead to power outages [8,9]. Therefore, it is very important to determine the optimal solution that minimises power losses and maintains voltage stability [10,11].

Notably, DG sizing and placement can be performed, for instance, through classical optimisation techniques, which might fail to tackle the problem's nonlinear and complex nature, it might also neglect the power losses and voltage stability issues when in tandem, thereby missing out on the optimal solution [12,13,14]. Equally, metaheuristic techniques, such as Ant Colony Optimization (ACO) and Particle Swarm Optimisation (PSO), have shown promising outcomes in addressing complex optimisation problems [15,16].Acordingly, in this paper, application of ACO technique to the problems of DG sizing and placement for loss minimization and voltage stability is presented.

2. METHODOLOGY

2.1 Mathematical Model Development of Ant Colony Optimization (ACO) algorithm

The Ant Colony Optimization (ACO) algorithm is a metaheuristic optimization technique that was first introduced by Marco Dorigo in his Ph.D. thesis in the 1990s (Ünal *et al.*, 2013). The algorithm is inspired by the foraging behaviour of real ants. The mathematical model development of ACO involves the following components:

$$P_{ij}^{(k)}(t) = \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}{\sum_q [\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}};\ j,q \in N_i^k \quad (1)$$

$$\eta_{ij} = \frac{1}{L_{ij}} \quad (2)$$

Where $P_{ij}^{(k)}(t)$ is the probabilistic transition rule of ant k to go from node i to node j at time t, $\tau_{ij}(t)$ is the pheromone trail deposited by k ant between node i and node j at time t, $\eta_{ij}(t)$ is the heuristic factor and it is further defined as the $\eta_{ij} = \frac{1}{L_{ij}}$, where L_{ij} is the distance or the length between node i and node j at time t, α is used to adjust the influence of the pheromone trail, β is used to adjust the influence of the heuristic information, q is the nodes that will be visited next after node i, N_i^k is the neighbourhood of decision variable for k ant or a tabu list in the memory of ant that records the nodes visited to avoid stagnations.

After each tour or iteration is completed, a local pheromone update is determined by each ant which is dependent on the route of an individual ant in the search space, and this is given as:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \rho\tau_0 \quad (3)$$

After all ants complete their tours, the global pheromone update takes place. This is where the best tour discovered by any ant significantly influences the pheromone distribution and this is given as:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \varepsilon\Delta\tau_{ij}(t) \quad (4)$$

Where $\tau_{ij}(t+1)$ is the pheromone after one tour or iteration, ρ is the pheromone evaporation constant, ε is the elite path weighting constant, τ_0 is the incremental value of pheromone of each ant and it is further given as $\tau_0 = \frac{1}{L_{ij}}$, $\Delta\tau_{ij}$ is the amount of pheromone for elite path and it is further given as:

$$\Delta\tau_{ij}(t) = \frac{Q}{L_{best}} \quad (5)$$

Where Q is a large positive constant, L_{best} is the shortest tour length or distance.

The ACO flowchart algorithm for optimal location and sizing of DG is given in Figure 1.

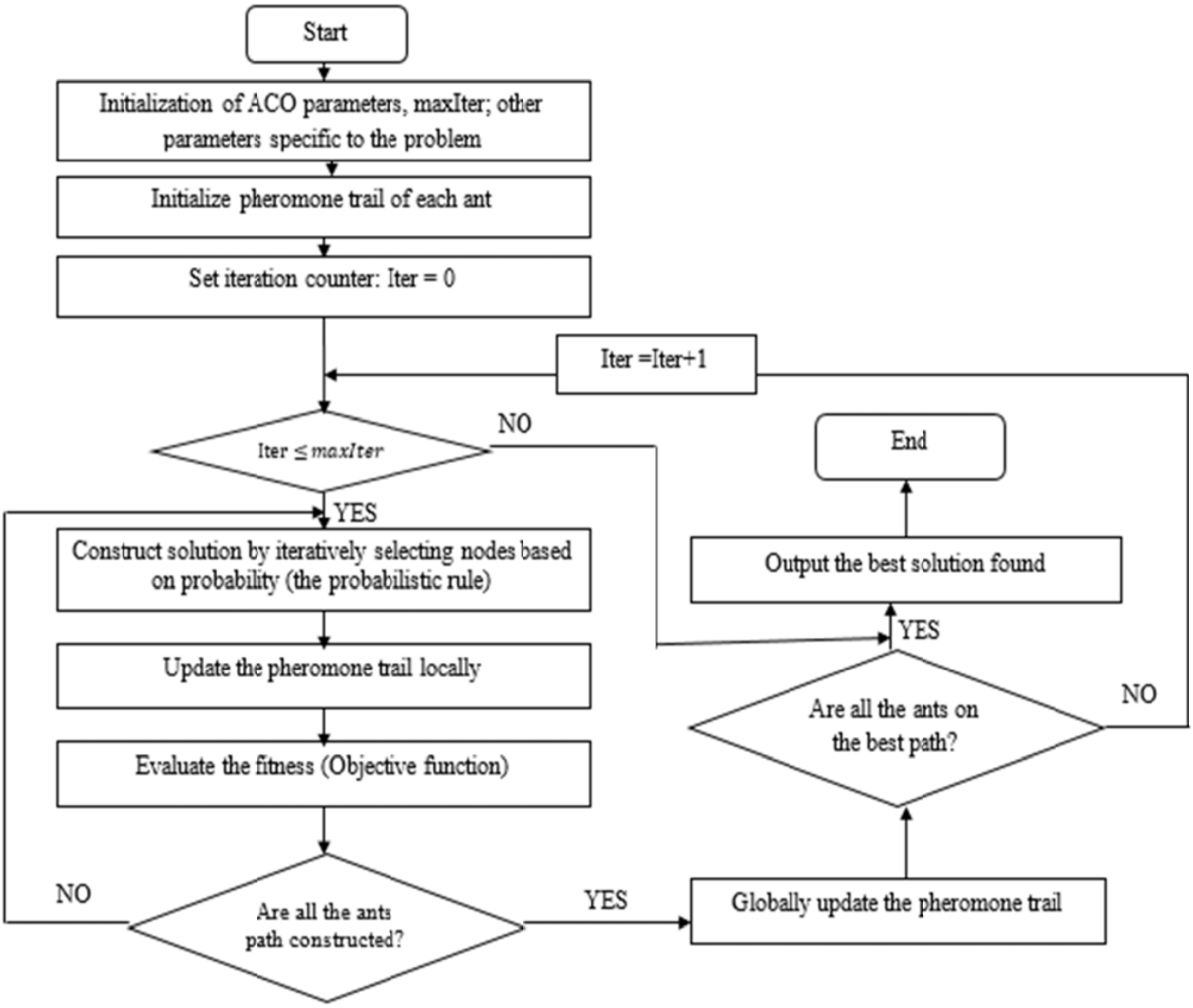

Figure 1: ACO flowchart algorithm for optimal location and sizing of DG

3.2 The parameters of the radial distribution network used in the study

The study used 11kV feeder network located in Aka in Uyo metropolis of Akwa Ibom State Nigeria. The feeder network is radial and the single-line diagram is presented in Figure 2. The bus dataset of the 11 kV feeder is given in Table 1 which showed total active power of 15930 kW along with total reactive power of 7715.29 kVar. The summary of the baseline parameters of the 11 kV feeder under the condition of no distributed generation (DG) is shown in Table 2. The parameter values in Table 2 are load flow analysis results obtained using the backward/forward sweep applied to the 11 kV network with no DG. The parameters values in Table 2 show that without DG, about 13.23716259 % of active power loss is witnessed along with 10.06491007 % of reactive power loss.

Table 1: Bus load data for the AKA 11 kV feeder

Bus ID	Bus Location	Bus Type	Voltage (kV)	Angle (Deg)	Transformer Rating (kVA)	Active Power Demand (kW)	Reactive Power Demand (kVAR)
1	Injection Substation	Slack Bus	11	0	-	-	-
2	IBB Road S/S	Load Bus	11	0	300	270	130.77
3	Akpa Ube S/S	Load Bus	11	0	500	450	217.94
4	MTN S/S	Load Bus	11	0	100	90	43.59
5	No Name	Load Bus	11	0	300	270	130.77
6	Wema Bank S/S	Load Bus	11	0	300	270	130.77
7	Johnson St S/S	Load Bus	11	0	500	450	217.94
8	Ndiya St S/S	Load Bus	11	0	300	270	130.77
9	Everyday Food S/S	Load Bus	11	0	100	90	43.59
10	FSTC S/S	Load Bus	11	0	500	450	217.94
11	Ukana Offot S/S	Load Bus	11	0	500	450	217.94
12	Andy Umana St S/S	Load Bus	11	0	300	270	130.77
13	GOTV S/S	Load Bus	11	0	100	90	43.59
14	Crunchies S/S	Load Bus	11	0	200	180	87.18
15	Aka Junction S/S	Load Bus	11	0	500	450	217.94
16	Sacred Heart S/S	Load Bus	11	0	300	270	130.77
17	Water Resources S/S	Load Bus	11	0	300	270	130.77
18	Nung Oko I S/S	Load Bus	11	0	300	270	130.77
19	MTN S/S	Load Bus	11	0	100	90	43.59
20	Market Road S/S	Load Bus	11	0	500	450	217.94
21	Ayara S/S	Load Bus	11	0	500	450	217.94
22	ST. Christopher S/S	Load Bus	11	0	300	270	130.77
23	Nung Oko II S/S	Load Bus	11	0	500	450	217.94
24	Incubation Centre S/S	Load Bus	11	0	200	180	87.18
25	Nung Atai S/S	Load Bus	11	0	300	270	130.77
26	Womi Estate S/S	Load Bus	11	0	500	450	217.94
27	Aka Community School I S/S	Load Bus	11	0	300	270	130.77
28	SPG Hotel S/S	Load Bus	11	0	100	90	43.59
29	Aka Community School II S/S	Load Bus	11	0	300	270	130.77
30	Aka Community School III S/S	Load Bus	11	0	300	270	130.77
31	Aka Idak Eyop S/S	Load Bus	11	0	500	450	217.94
32	Idak Eyop Mpiak Ring Road S/S	Load Bus	11	0	300	270	130.77

33	Multichoice S/S	Load Bus	11	0	100	90	43.59
34	Samuel Peter S/S	Load Bus	11	0	200	180	87.18
35	Mbietebe Primary School S/S	Load Bus	11	0	300	270	130.77
36	Edet Effiong S/S	Load Bus	11	0	300	270	130.77
37	Obio Etoi S/S	Load Bus	11	0	300	270	130.77
38	Mbietebe II S/S	Load Bus	11	0	300	270	130.77
39	Mbietebe Market S/S	Load Bus	11	0	300	270	130.77
40	Redemption Academy Avenue S/S	Load Bus	11	0	500	450	217.94
41	Mbietebe Nna Umiang S/S	Load Bus	11	0	300	270	130.77
42	Mbiokporo S/S	Load Bus	11	0	500	450	217.94
43	Ima Abasi S/S	Load Bus	11	0	500	450	217.94
44	Ikot Akpa Abia I S/S	Load Bus	11	0	300	270	130.77
45	Ikot Akpa Abia II S/S	Load Bus	11	0	300	270	130.77
46	Idak Editan S/S	Load Bus	11	0	300	270	130.77
47	Ikot Iko I S/S	Load Bus	11	0	300	270	130.77
48	Ikot Iko II S/S	Load Bus	11	0	300	270	130.77
49	Afaha Ikot Akpa Edu S/S	Load Bus	11	0	300	270	130.77
50	Oboyo Ikot S/S	Load Bus	11	0	200	180	87.18
51	Itak Nyayah S/S	Load Bus	11	0	300	270	130.77
52	Nsiak Ndap S/S	Load Bus	11	0	300	270	130.77
53	Emmanuel Umoren S/S	Load Bus	11	0	300	270	130.77
54	Udo Kang S/S	Load Bus	11	0	500	450	217.94
55	PDP S/S	Load Bus	11	0	300	270	130.77
56	Atan Offot S/S	Load Bus	11	0	300	270	130.77
						15930	7715.29

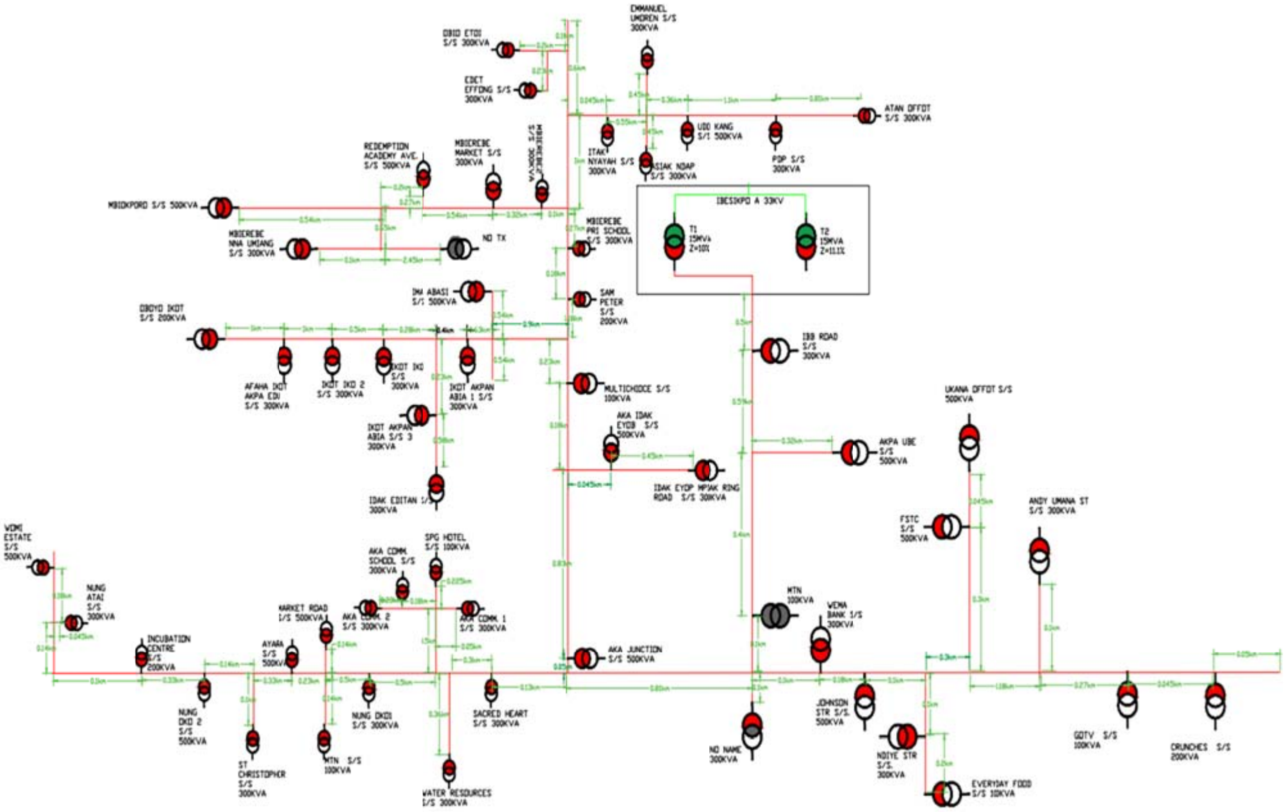

Figure 2: The Single-line diagram of the case study AKA 11kV distribution feeder network (DFN).

Table 2 The summary of the baseline parameters of the 11 kV feeder

The 11 kV Feeder Parameters	The Parameter Values for the baseline case; no DG
Total real power loss (kW)	2108.68
Percentage of total real power loss to the total real power (%)	13.23716259
Total reactive power loss (kVar)	776.537
Percentage of total reactive power loss to the total reactive power (%)	10.06491007
Minimum voltage (pu)	0.8621
Minimum voltage bus number	56
Maximum Voltage (pu)	0.9834
Maximum voltage Bus number	2
Voltage deviation index (%)	11.28

3. RESULTS AND DISCUSSIONS

The ACO method was used for the sizing and optimal placement of the DGs on the 11 kV feeder and the results were obtained for the cases of 1 DG install, 2 DGs, install and 3 DGs installed. The key performance metrics obtained through simulations using ACO algorithm for a scenario with 30% DG penetration is presented in Table 3. The voltage profile comparison with increasing DG penetration using ACO is presented in Figure 3.

Table 3: ACO-optimized DG Placement Results (30% Penetration)

Parameters	Base Case	1 DG	2 DG	3 DG

Toal real power loss (kW)	2108.68	1050	998	996
Total reactive power loss (kVar)	776.537	387	368	367
Real power loss reduction (%)	-	50.21	52.06	59.88
% Reactive power loss reduction	-	50.16	52.10	59.95
Minimum voltage (pu)	0.8621	0.9076	0.9082	0.9098
Minimum voltage bus number	56	50	56	42
Maximum Voltage (pu)	0.9834	0.9881	0.9883	0.9881
Maximum voltage bus number	2	2	2	2
Voltage deviation index (%)	11.28	7.63	7.40	7.51
DG location (Bus No.)	-	50	49, 37	47, 56, 21
DG real power size (kW)	-	4779	2232, 2166	1399, 1585, 1305
DG reactive power size (kVAR)	-	2315	875, 748	270, 509, 579

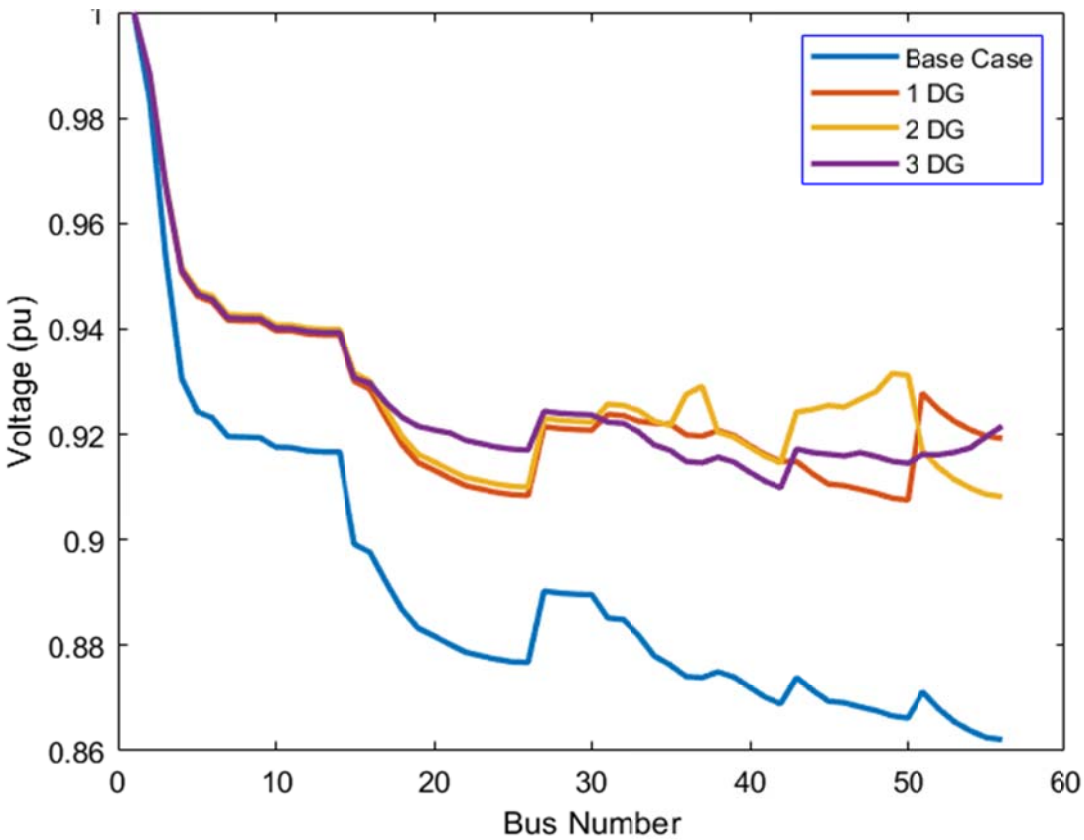

Figure 3: Then voltage profile with 1 DG, 2 DG and 3 DG placement using ACO.

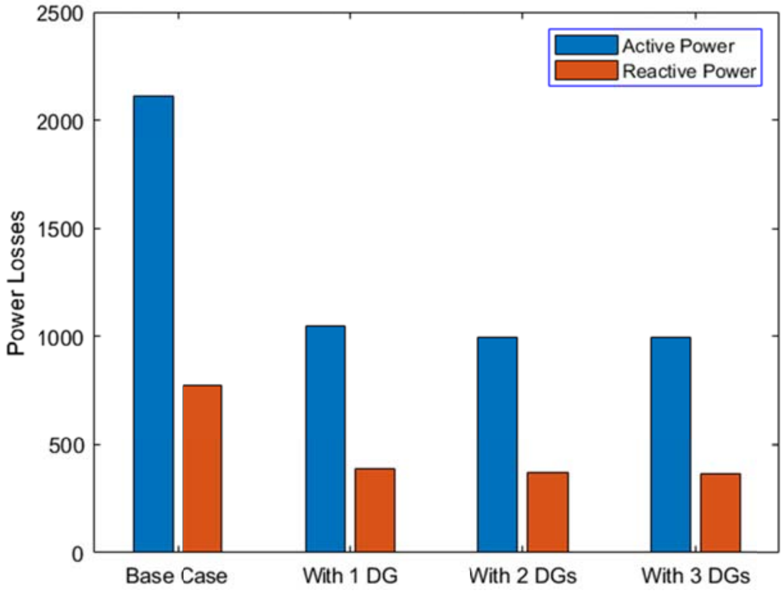

Figure 4: The power loss with 1 DG, 2 DG and 3 DG placement using ACO.

The voltage profile at each bus for the base case and with 1, 2, and 3 DGs is shown in Figure 4, illustrating the impact of DG on voltage stability and power quality. The impact of DG on power losses is illustrated in Figure 3, highlighting the reduction in real and reactive power losses as the number of DG units increases using ACO algorithm.

Based on Table 3, the ACO algorithm results for optimizing DG placement at 30% penetration showed that the total real power loss decreased from 2108.68 kW in the base case to 1050 kW when the DG is 1, 998 kW when the DG is 2 and 996 kW when the DG is 3. Similarly, the total reactive power loss, as shown in Table 3 reduced from 776.537 kVar to 387 kVar when the DG is 1, 368 kVar when the DG is 2 and 367 kVar when the DG is 3. Accordingly, with the implementation of the ACO algorithm, the real power was reduce by 50.21% when the DG is 1 to 52.06% when the DG is 2 and 52.76% when the DG is3. Again, with the implementation of the ACO algorithm, the reactive power was reduce by 50.16% when the DG is 1 to 52.10% when the DG is 2 and 52.73% when the DG is 3. There was improvement in the minimum voltage from 0.8621 pu in the base case to 0.9076 pu when the DG is 1, 0.9082 pu when the DG is 2 and 0.9098 pu when the DG is 3. Also, the maximum voltage remained fairly constant around 0.9834 to 0.9883 pu across all scenarios. The VDI which is voltage deviation index, improved from 11.28% in the base case to 7.63% when the DG is 1, 7.40% when the DG is 2 and 7.51% when the DG is 3. With 1 DG, it was placed at bus 50 with a real power size of 4779 kW and a reactive power size of 2315 kVar; with 2 DGs, they were placed at buses 49 and 37, with real power sizes of 2232 kW and 2166 kW, and reactive power sizes of 875 kVar and 748 kVar; with 3 DGs, they were placed at buses 47, 56, and 21, with real power sizes of 1399 kW, 1585 kW, and 1305 kW, and reactive power sizes of 270 kVar, 509 kVar, and 579 kVar. The addition of DG units significantly reduced both real and reactive power losses while improving the voltage profile and reducing voltage deviation in the system, with these benefits becoming more pronounced as the number of DG units increased.

4. CONCLUSION

The Ant Colony Optimization (ACO) algorithm is presented in this paper and it is specifically applied to optimally size and locate distributed generator (DG) on a power network. The study used a case study feeder network in Akwa Ibom State and load flow analysis was conducted for the base case scenario where no distributed generator was installed. The baseline parameters of the feeder network were captured and then compare with those obtained when one, two and three DGs were optimally sized and located in the feeder network using the ACO algorithm. The results showed that using the ACO algorithm greatly improved the feeder power system performance; the real and reactive power losses were greatly reduced and the voltage deviation index significantly improved. In all, the study clearly demonstrated that the ACO can be used to address some of the challenges of DG sizing and placement in power distribution networks.

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