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Optimal location and sizing of renewable distributed generators (DG) in enugu distribution network

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Abstract
This paper addresses the traditional problem of optimal location and sizing of renewable Distributed generators (DGs) in radial distribution networks. Numerous optimization techniques have been used by several researchers to establish the optimal placement and sizing of DGs to alleviate the power loss in the system. However, in terms of the reduction of active power loss, the performance of these algorithms are weaker. The premature convergence, the precision of the output, and the complexity are a few major drawbacks of these optimization techniques. Therefore, this paper proposes a non-linear optimization technique for the determination of the optimal locations and sizes of DGs with the objective of active power loss and operation cost minimization. To solve this model, General Algebraic Modeling System (GAMS) software was employed in conjunction with the IPOPT solver. A 26-bus Enugu distribution network was used to model the efficiency of the proposed method. The obtained results from optimal placement of DGs shows a reduction in power losses, improved voltage profile and reduced cost of operation of the network.

Keywords: Distributed generators, distribution network, optimal placement and sizing

1. Introduction

The increasing demand for electric power, coupled with governmental policy for "green" energy and emissions reduction – responsible for the greenhouse effect – have led to significant modifications in the electric power generation. Presently, around the world, electricity is mostly produced by large-scale plants that operate using conventional sources of energy, such as fossil fuels, hydraulic and thermal technologies. According to Prakash and Khatod (2016), electric plants are usually located far from final consumers and, therefore, energy losses associated with transmission lines increase. The voltage limit can also be exceeded by transmission of electric power over a long distance. These problems have necessitated the adoption of Distributed Generation (DG) to become a local solution for medium- and low-voltage power systems (Mahdad and Srairi, 2016). DGs enable the injection of active and reactive power closer to consumers, which can produce benefits in terms of quality of service (Elmitwally, 2013). Integrating DGs into the electric system has both positive and negative effects because they modify the behavior of the state variables of the grid, which absolutely depend on their location and sizing in the power system (Grisales, Restrepo and Jaramillo, 2017).

When the distributed generation is used in addition to the grid supply it reduces electric energy units drawn by utility from the grid and thereby reduces emission of many harmful gases such as CO, Particulate Matter (PM) and Unburned Hydrocarbons (UHC). Apart from the environmental benefits, DG has got many technical benefits such as reduction in line losses, improved system performance, increase in the efficiency, and improved profile of voltage and grid reinforcement (Mithulananthan, Than and Le, 2004). Piccolo and Siano (2009) stated that, DG is economically beneficial in terms of less maintenance, reduction in the investment cost to upgrade the system in case of increase of load and many intangible benefits due to improved environment. More distributed generation (DG) is expected to be connected to the distribution network and is considered to have the potential of improving system integrity, reliability and efficiency (Yu, Chung, Wong and Zhang, 2009). Placing optimal sizes of distributed generation units in optimal places can have significant impacts on the voltage level and loss levels in distribution networks. On the other hand, placing a non-optimal size of distributed generation in a non-optimal place may compromise system stability and reliability, eventually leading to higher levels of losses than the network had prior to installation of the distributed generation. How to optimally integrate DG in the current network is a common challenge for the distribution system operators (DSOs) in countries with a high DG penetration level or high potential increase in the DG penetration level.

Various authors have carried out studies on the planning and optimal siting and sizing renewable of distributed generators in electric distribution networks. Due to the increasing rate of DG integration in the distribution system, distribution network operators (DNOs) are at the centre of the planning strategies towards maximizing renewable energy penetration in the distribution network through optimal location of DGs. Kaur, Kumbhar and Sharma (2014), stated that the optimal location of the distributed generators was introduced in order to reduce the power losses. Ghosh and Ghoshal (2010) presented a method for optimal sizing and optimal placement of renewable energy, implementing an iterative search approach along with the Newton Raphson method. Manikanta, Mani, Singh and Chaturvedi (2016) employed an adaptive quantum-inspired evolutionary algorithm to locate and size distributed generators to reduce power losses in the networks. Babu and Singh (2016) described a multi-objective function to minimize the real power and reactive losses and to enhance the voltage profiles using the General Algebraic Modeling System (GAMS). Meena, Gupta and Niazi (2017) proposed an improved variant of the genetic algorithm for optimal planning of wind power generators considering reactive power dispatch capabilities. Essallah, Khedher and Bouallegue (2019) developed a Bat algorithm for optimal placement and sizing of the distributed energy resources, considering load variations to minimize power loss and enhance voltage profile. Prabha and Jayabarathi (2016) proposed, an invasive weed optimization algorithm to solve this same problem. Jamil and Annees (2016) proposed an analytical approach for optimal size and location of solar photovoltaic. Das and Mukherjee (2016) focused on reducing powerlosses and improving the voltage profiles. Gozel and Hocaoglu (2009) presented the optimal distributed generator placement in radial distribution networks based on a symbiotic organism's search algorithm to reduce the network losses. Sa'Ed, Amer, Bodair, Baransi, Zizzi (2019) developed analytical expressions to determine the optimal sizes and the locations of DGs considering the minimization of power loss, and four different power loss formulas have been employed to calculate the power loss of the system. Concerning the minimization of power loss as the objective, an analytical technique centered on a loss sensitivity factor is utilized in finding the optimal sitting and sizing by Acharya, Mahat and Mithulananthan (2006) and the produced results have been compared with another two analytical methods. A simplified analytical technique has been proposed by Rueda-Medina, Franco, Rider and Padilha (2013) to optimally integrate DGs to alleviate the power loss in distribution networks and the power loss reduction results have been analyzed with another four methods for one, two, and three DGs.

Kaur, Kumbhar and Sharma (2014) used the exact loss equation-based analytical technique to find the optimal size and the location of a single DG in three different distribution networks. The mixed-integer linear programming (MILP) approach has been used by Vita, Alimardan and Ekonomu (2016) to determine the optimal placement and sizing of DGs in radial distribution systems. Vita (2017) used the mixed-integer nonlinear programming (MINLP) technique to identify optimal placement and sizing of DGs with the intention of minimization of network power loss. In simplifying the problem of DG location and sizing, most researchers in the literatures often either fix the number of DGs or the sizes. The proposed method in this paper eliminates this restriction by allowing the algorithm to objectively search through the entire search space without restricting the possible number of DGs or the capacity of the DGs in deriving the optimum combination of the number, the site and size of DGs to minimize the real power loss in the system.

2.0 Material and methods

2.1 Objective Function

The objective of the proposed operation problem is to minimize the total operational cost while using the power loss index to identify buses with severe losses for placement of DGs.

$$Minimise\ F_{obj} = \sum_{i=1}^{NB} \sum_{Gen=1}^{NGen} \sum_{c=1}^{Nc} C_{Gen}^{i} P_{G_{Gen}}^{i} + \sum_{i=1}^{NB} \sum_{Gen=1}^{NGen} \sum_{c=1}^{Nc} C_{Gen}^{i} P_{DG_{Gen}}^{i} \tag{1}$$

The objective function is made up of two parts: the first part represents the cost function for power derived from sub-station generator. The second part is the cost function for power supply from the renewable energy source and in this case, solar power was adopted for the work.

2.1.1. Equality Constraints

The equality constraints

$$\sum_{Gen=1}^{Gen} P_{g(Gen)} + \sum_{Gen=1}^{Gen} P_{dg(Gen)} - P_l^i = \sum_{line=1}^{line} \sum_{j=1}^{i} P_{ij\,(line,j)} \tag{2}$$

$$\sum_{Gen=1}^{Gen} Q_{g(Gen)} + \sum_{Gen=1}^{Gen} Q_{dg(Gen)} - Q_l^i = \sum_{line=1}^{line} \sum_{j=1}^{i} Q_{ij\,(line,j)} \tag{3}$$

$$P_{i,j} = \frac{V_i^2 (\cos\theta_{i,j}) - V_i V_j \cos(\delta_i - \delta_j + \theta_{i,j})}{Z_{ij}} \tag{4}$$

$$Q_{i,j} = \frac{Q_i^2 (\sin\theta_{i,j}) - V_i V_j \sin(\delta_i - \delta_j + \theta_{i,j})}{Z_{ij}} \tag{5}$$

$$\theta_{ij} = \tan^{-1} \frac{X}{R} \tag{6}$$

$$Z_{ij} = \sqrt{X^2 + R^2} \tag{7}$$

Constraints 2 and 3 apply Kirchhoff's law in the analysis. Constraints 2 and 3 ensure the active and reactive power balances in system nodes. Equations 4 and 5 outline the solution of active and reactive power flow in the line.

2.1.2. Inequality Constraints

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \tag{8}$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \tag{9}$$

$$P_{dgi}^{\min} \le P_{dgi} \le P_{dgi}^{\max} \tag{10}$$

$$Q_{dgi}^{\min} \le Q_{dgi} \le Q_{dgi}^{\max} \tag{11}$$

$$P_{ij} \le P_{ij}^{\max} \tag{12}$$

$$Q_{ij} \le Q_{ij}^{\max} \tag{13}$$

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{14}$$

$$\delta_i^{\min} \le \delta_i \le \delta_i^{\max} \tag{15}$$

Constraints (8) -(9) set the upper bounds for active and reactive power of substation. Also, constraints (10) -(11) limit the active and reactive power generation of PVs. The PVs generation depends on the solar irradiance. The active and reactive power flow limit in the line which ensures the security of the system is constrained by equations (12) -(13). Constraints (14) -(15) determine the acceptable range of voltage and angle at the buses.

2.2. Optimal Placement of DG

The essence of DGs in distribution networks is to increase the efficiency and network reliability while reducing power loss in the system. The power loss equation by Mokryani (2015), shown below will be modeled for optimal placement of DGs in distribution network.

$$P_L = G_{ij}\left[\left(V_i^2 + V_j^2\right) - 2V_iV_j\cos\left(\theta_i - \theta_j\right)\right] \tag{16}$$

P_L represents the power loss in all the branches of the network under a peak load scenario of demand; V_i and V_j are the voltage magnitudes at nodes i and j respectively; θ_i and θ_j, the voltage angles at nodes i and j, respectively; G_{ij}, the magnitude of admittance associated with line connected between i and j nodes.

The following steps have been followed for optimal placement of DG in distribution network:

- Run the base case power flow of the network and determine the power loss in each node using equation (16).
- The buses are ranked in descending order based on the power loss.
- Buses having high priority, proximity to load and other generation units is considered for placing the DG units for the distribution network.

2.3 Case Study

The proposed method is applied and implemented on a 26-bus 33/11kV Enugu distribution network. The network data is available in appendix I and II. The single line diagram is shown in fig1. Also the bus names and locations of the Enugu distribution network line diagram are presented in appendix III. The network is comprised of four feeders which were supplied from New heaven 330kV transmission station. A 60MVA 132/33kV transformer supplies the feeder connecting Government house, Achara layout, Emene, Trans-Ekulu, Independence layout and New NNPC loads. Another 60MVA 132/33kV transformer was connected to the feeder supplying power to Ituku ozalla, thinker’s corner and Nike lake. A 30MVA 132/33kV transformer was also connected to the feeder supplying Kingsway I and Ebeano loads. The fourth feeder connecting Kingsway II and Ninth Mile are been supplied by a 30MVA 132/33kV transformer. Non-linear programming has been adopted for the solution of the problem. The proposed method is applied to the above mentioned distribution network and implemented in GAMS and solved using IPOPT solver (Brooke, Kendrick, Meeraus and Raman, 1998) on a PC with Core i7 CPU and 16GB of RAM.

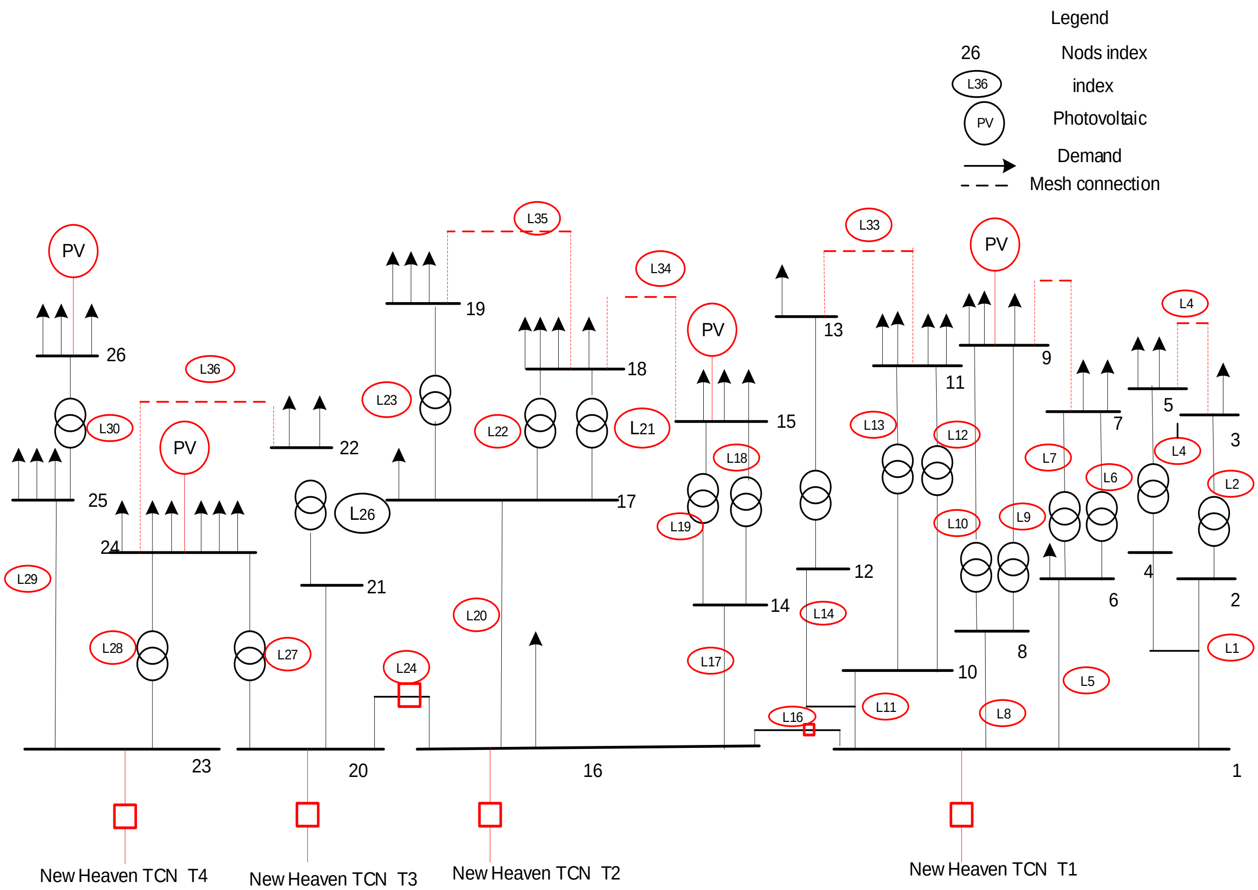

Figure 1: 26-bus Enugu Distribution Network with candidate PVs

3.0 Results and Discussions

3.1. DG Placement: Enugu electricity distribution network is divided into four sub-distribution network. Each sub-distribution network is fed from a separate transformer from the transmission station in New Heaven. Optimal placement of DG is done in each of the sub-distribution network by considering the branch with the highest power loss using equation 16. The power loss is a guiding factor for optimal placement of DG in the network. The first step involves running a load flow in the network and the corresponding power losses along the branches were recorded. The power losses were arranged in descending order of magnitude so as to easily locate the branch with the highest losses. The results show that, Gariki bus which supplies power to Satellite, Army and Gariki, recorded the highest power loss of 1.1MW, therefore this informed the decision to place the DG at Gariki bus. After placing DG in Gariki bus, load flow was run in the network again to ascertain the next optimal location for DG placement. From the results, Kingsway sub-station bus recorded the highest power loss of 0.5MW and therefore was chosen as the best location for DG placement. Kingsway sub-station bus supplies power to loads connected Prison, Onitsha Road, Gulf course, Hill top, Coal camp and Power house.

With the placement of DG in Kingsway sub-station, a load flow was performed in the network again so as to determine the power losses in the buses. Results recorded from that shows that Ninth mile bus recorded the highest power loss of 0.5MW and this gives the optimal location for the DG placement. Ninth mile bus supplies power to loads connection at Eziagu, Ajali and Abor. A DG was placed in Ninth mile bus and a load flow performed again to ascertain the network behavior with respect to power losses. The results depicts that Trans-Ekulu bus recorded the highest power loss of 0.4MW. Loads from Nowas, Phase 6 and Dhamija are connected to Trans-Ekulu injection substation. Again, load flow analysis was performed after DG placement at Trans-Ekulu injection sub-station. The records of power losses depict a drastic reduction in power losses in the network. The four DGs were placed in each of the four sub-distribution network. The magnitude of the power losses in the buses defined the choice and order for optimal placement of the DG. The presence of DGs in the network not only reduced the power losses, but also reduced the cost of operation of the network as less power will be purchased from the costlier substation generators.

3.2. Network characteristics with and without DG: The table 1 below shows the Cost of operation and power loss in the network when DG is connected to the network in stages and when DG is not connected to the network.

Table 1: Network characteristics with and without DG

Number of DG	Without DG	One DG	Two DGs	Three DGs	Four DGs
Bus (Location)	-	Gariki	-Gariki -Kingsway Injection S/S	-Gariki -Kingsway Injection S/S -Ninth Mile	-Gariki -Kingsway Injection S/S -Ninth Mile -Trans-Ekulu Injection S/S
Power Loss (MW)	10.1	6.1	4.5	4.1	2.6
Cost of Operation (₦/MW)	1181.2	1099.42	1030.54	968.13	900.17

Table 2: DG size at the buses in different locations

Bus Location for DGs	Gariki	Kingsway Injection S/S	Ninth Mile	Trans-Ekulu Injection S/S
Total Dispatched Power by DGs (MW)	10	11.2	9.7	10.2

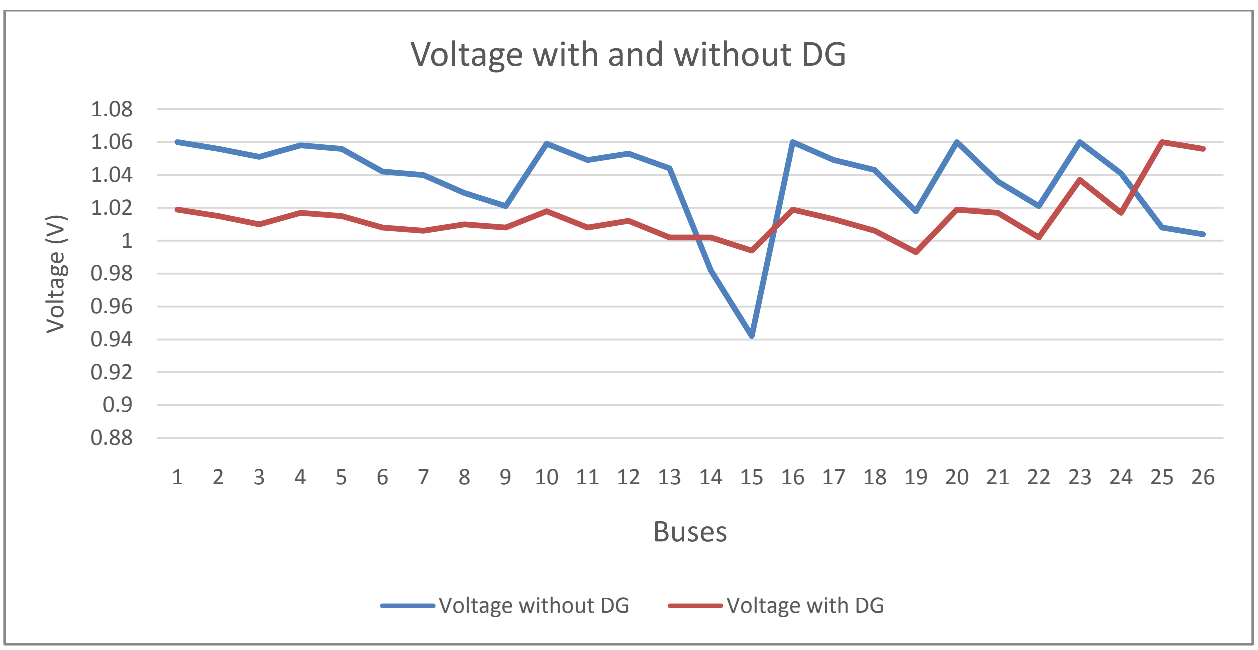

Fig 2: Voltage Profile with and without DG

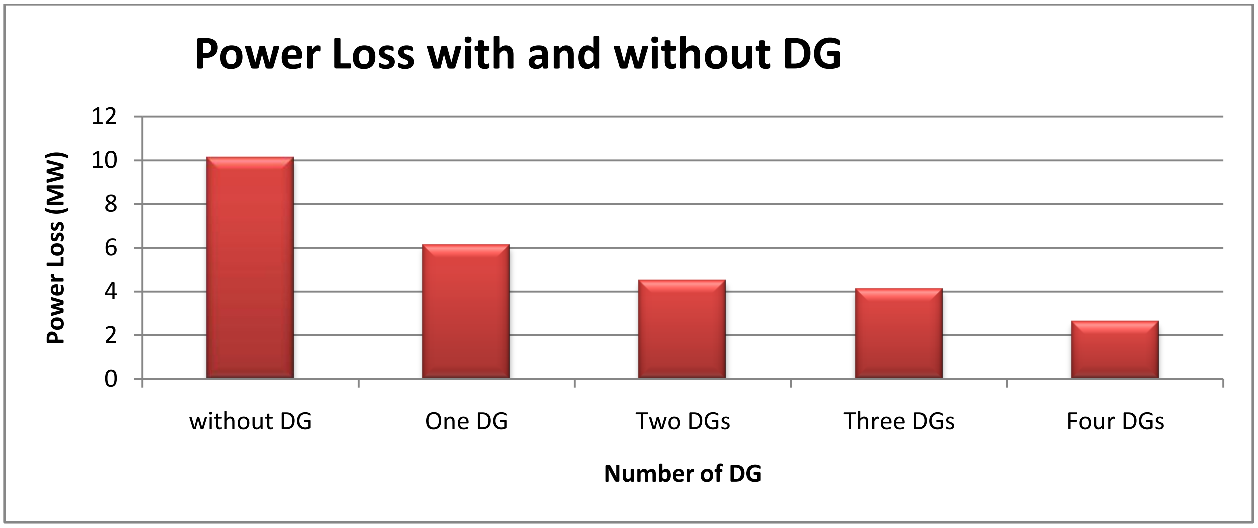

Fig 3: Power loss with and without DG

The network characteristics with and without DG are presented in the figures above. After allocating DG in optimal sites and performing a load flow analysis, the base case (without DGs) voltage profile is compared with the DG connected distribution system is shown in figure 2. The results show a significant improvement in the network voltage profile when DG was placed in the network as compared to the network without DG.

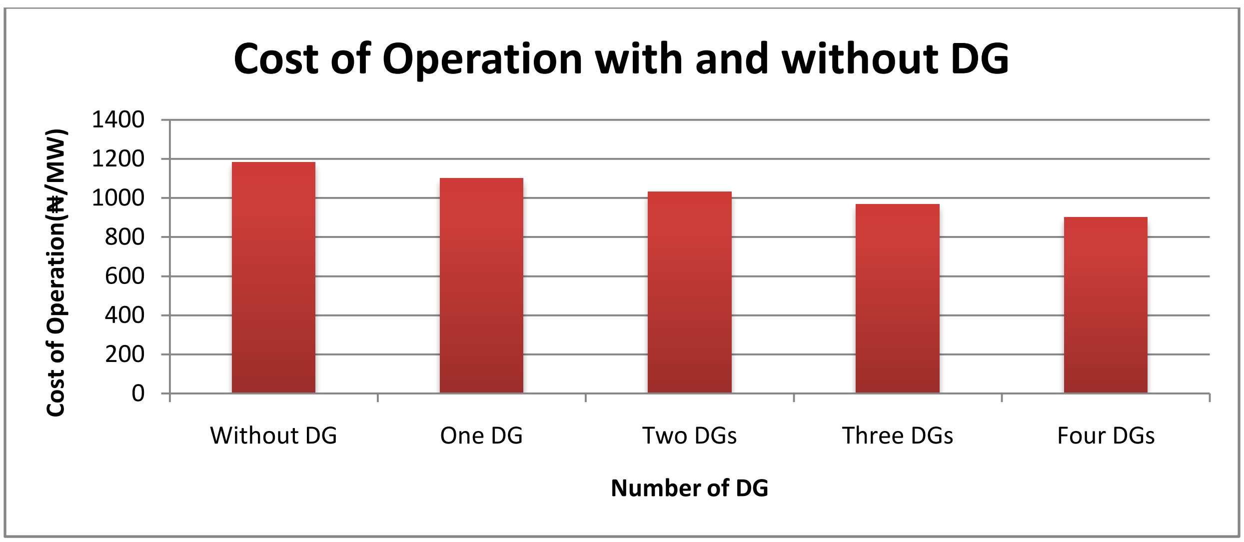

Fig 4: Operation cost with and without DG

DG was placed in the network. The operation cost also reduced with optimal DG placement because most of the power will be supplied by the DG (renewable energy type) instead of the sub-station generator that have a higher operational cost.

4.0. Conclusion

The proper placement and sizing of DGs in a power distribution system plays a significant role in reducing the total real and reactive losses as well as improves the voltage profile within the system. In this paper, an optimization method for determining the optimal locations and capacities of distributed generated resources in a power distribution network using non-linear Optimization was presented. The optimization provides the optimal DG integration locations and the DG sizes such that the active power loss of the network system is minimized. The analysis was performed on the 26-bus Enugu distribution network. General Algebraic Modeling System (GAMS) software was used to implement the network. Results obtained showed a significant reduction in the total real and reactive power losses as well as improvement in the voltage profile of the power distribution network as a result of the DGs. The impact of the optimally located and sized DGs was also significantly felt in the network as compared to the absence of DG in the network.

List of Symbols

a)	*Indices*
i,j	Buses
Gen	Generators
L	Load
Line	Distribution line
Dg	set of PV generators
b)	*Parameters*
C_{Gen}^{i}	Price offered by PVs and sub-station generators to increase/decrease active power at bus i
P_{gi}^{min} , P_{gi}^{max}	Minimum and maximum active power for substation generators
P_{dgi}^{min} , P_{dgi}^{max}	Minimum and maximum active power for PV generators
Q_{gi}^{min} , Q_{gi}^{max}	Minimum and maximum reactive power for substation generators
Q_{dgi}^{min} , Q_{dgi}^{max}	Minimum and maximum re active power for PV generators
P_{ijc}^{*}	Maximum active power flow in distribution line
Q_{ijc}^{*}	Maximum reactive power flow in distribution line
V_i^{min} ,	Minimum value of voltage at bus *I*
V_i^{max}	Maximum value of voltage at bus *i*
δ_i^{min} ,	Minimum value of voltage angle
δ_i^{max}	Maximum value of voltage angle
P_l^i ,	Active power of load demand at bus *I*
Q_l^i	Reactive power of load demand at bus *i*
c)	*Variables*
P_{gi} ,	Active power of substation generator at each bus
P_{dgi}	Active power of PVs at each bus
Q_{gi} ,	Reactive power of substation generator at each bus
Q_{dgi}	Reactive power of PVs at each bus
P_{ij} ,	Active power flow in distribution line
Q_{ij} ,	Reactive power flow in distribution line
V_i	Voltage at bus *i*
δ_i	Voltage angle at bus *i*

References

Acharya, N.; Mahat, P.; Mithulananthan, N. (2006), An analytical approach for DG allocation in primary distribution network. International Journal Electrical. Power Energy System, 28, 669–678.

Babu, P.V.; Singh, S. 2016), Optimal Placement of DG in Distribution network for Power loss minimization using NLP & PLS Technique. Energy Procedia, 90, 441–454.

Das, B.; Mukherjee, V.; Das, D. (2016), DG placement in radial distribution network by symbiotic organisms search algorithm for real power loss minimization. Applied Software Computer, 49, 920–936.

Elmitwally A. (2013). A new algorithm for allocating multiple distributed generation units based on load centroid concept. Alexandr Engineering Journal;52(4):655–63. doi:https://doi.org/10.1016/j.aej.2013.08.011

Essallah, S.; Khedher, A.; Bouallegue, A. (2019), Integration of distributed generation in electrical grid: Optimal placement and sizing under different load conditions. Computer Electrical Engineering, 79, 106461.

Ghosh, S.; Ghoshal, S.P.; Ghosh, S. (2010) Optimal sizing and placement of distributed generation in a network system. Int. J. Electr. Power Energy Syst. **2010**, 32, 849–856.
Gözel, T.; Hocaoglu, M.H. (2009), An analytical method for the sizing and siting of distributed generators in radial systems. Electrical. Power System, 79, 912–918.
Grisales Noreña LF, Restrepo Cuestas BJ, Jaramillo Ramirez FE. (2017) Location and sizing of distribted generation: a review. Ciencia e Ingeniería Neogranadina 2017;27(2):157–76.doi: https://doi.org/10.18359/rcin.2344.
Jamil, M.; Anees, A.S.(2016) Optimal sizing and location of SPV (solar photovoltaic) based MLDG (multiple location distributed generator) in distribution system for loss reduction, voltage profile improvement with economical benefits. Energy, 103, 231–239.
Kaur, S.; Kumbhar, G.; Sharma, J. A (2014) MINLP technique for optimal placement of multiple DG units in distribution systems. International Journal of Electrical Power Energy System, 63, 609–617.
Kaur, S.; Kumbhar, G.; Sharma, J. A (2014). MINLP technique for optimal placement of multiple DG units in distribution systems. International Journal Electrical Power Energy System, 63, 609–617.
Mahdad B, Srairi K. (2016), Adaptive differential search algorithm for optimal location of distributed generation in the presence of SVC for power loss reduction in distribution system. Engineering Science Technology, International Journal 2016;19(3):1266–82. doi: https://doi.org/10.1016/j.jestch.2016.03.002.
Manikanta, G.; Mani, A.; Singh, H.; Chaturvedi, D. (2016), Placing distributed generators in distribution system using adaptive quantum inspired evolutionary algorithm. In Proceedings of the Second International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), Kolkata, India, 23–25 September 2016; pp. 157–162.
Meena, N.K.; Swarnkar, A.; Gupta, N.; Niazi, K. (2017), Wind Power Generation Planning by Utilizing the Reactive Power Capabilities of Generators. In Proceedings of the Asian Conference on Energy, Power and Transportation Electrification (ACEPT), Singapore, 24–26 October 2017; pp. 1–6.
Mithulananthan N., Than O. and Le V.P. (2004). Distributed generator placement in power distribution using genetic algorithm to reduce losses. *Thammasat international journal of science and technology*; 9(3), pp. 55-62.
Mokryani G. (2015). ‘‘Active distribution networks planning with integration of demand response’’ *Solar Energy* 122 (2015) 1362-1370
Piccolo A. and Siano P. (2009). Evaluating the impact of network investment deferral on distributed generation expansion. *IEEE Transaction on power system*; 24(3), pp. 1559-1567.
Prabha, D.R.; Jayabarathi, T. Optimal placement and sizing of multiple distributed generating units in distribution networks by invasive weed optimization algorithm. Ain Shams Engineering Journal **2016**, 7, 683–694.
Prakash P, Khatod DK (2016). Optimal sizing and siting techniques for distributed generation in distribution systems: a review. Renewable Sustainable Energy Rev 2016; 57:11–30. doi:https://doi.org/10.1016/j.rser.2015.12.0.
Rueda-Medina, A.C.; Franco, J.F.; Rider, M.J.; Padilha-Feltrin, A.; Romero, R. (2013), A mixed-integer linear programming approach for optimal type, size and allocation of distributed generation in radial distribution systems. Electrical Power System, 97, 133–143.
Sa’Ed, J.A.; Amer, M.; Bodair, A.; Baransi, A.; Favuzza, S.; Zizzo, G. A (2019), Simplified Analytical Approach for Optimal Planning of Distributed Generation in Electrical Distribution Networks. Applied Science, 9, 5446.
Siano, P and G. Mokryani, (2013), "Evaluating the benefits of optimal allocation of wind turbines for distribution network operators," IEEE Systems Journal, vol. 9, no. 2, pp. 629-638.
Vita, V. (2017), Development of a Decision-Making Algorithm for the Optimum Size and Placement of Distributed Generation Units in Distribution Networks. Energies, 10, 1433.
Vita, V.; Alimardan, T.; Ekonomou, L. (2016). The Impact of Distributed Generation in the Distribution Networks’ Voltage Profile and Energy Losses. In Proceedings of the 2015 IEEE European Modelling Symposium (EMS), Madrid, Spain, 6–8 October 2015; IEEE: Piscataway, NJ, USA; pp. 260–265.
Yu, G., Chung, C.Y., Wong K.P and Zhang, J.H. (2009). “A chance constrained transmission network expansion planning method with consideration of load and wind farm uncertainties,” *IEEE Trans. Power System*, vol. 24, no. 3, pp. 1568–1576.

Appendix I

Network Line input parameters in PU

Line	Branch connection	Resistance (Ω)	Reactance (Ω)	Line limit (MW)
L1	1-2	0.104628	0.018697	0.3
L2	2-3	0.123967	0.022153	0.075
L3	1-4	0.104628	0.018697	0.3
L4	4-5	0.158678	0.028356	0.075
L5	1-6	0.2350	0.042003	0.3
L6	6-7	0.059504	0.010634	0.075
L7	6-7	0.059504	0.010634	0.075
L8	1-8	0.297521	0.053168	0.3
L9	8-9	0.148760	0.026584	0.075
L10	8-9	0.148760	0.026584	0.075
L11	1-10	0.003223	0.000576	0.30
L12	10-11	0.123967	0.022153	0.15
L13	10-11	0.123967	0.022153	0.15
L14	1-12	0.133388	0.023837	0.30
L15	12-13	0.178512	0.031901	0.15
L16	1-16	0.0004959	0.0000886	0.30
L17	16-14	0.548099	0.169429	0.30
L18	14-15	0.619835	0.110767	0.15
L19	14-15	0.619835	0.110767	0.15
L20	16-17	0.111570	0.019938	0.30
L21	17-18	0.386777	0.069118	0.15
L22	17-18	0.386777	0.069118	0.15
L23	17-19	0.495868	0.088613	0.075
L24	16-20	0.0004959	0.0000886	0.30
L25	20-21	0.322314	0.057599	0.15
L26	21-22	0.203306	0.036331	0.075
L27	20-24	0.079339	0.014178	0.30
L28	23-24	0.322314	0.057599	0.15
L29	23-25	0.758678	0.01038	0.30
L30	25-26	0.069421	0.012406	0.15

Appendix II

Load Demand at the buses in PU

Bus	Active Power (MW)	Reactive Power (MW)
1	0	0
2	0	0
3	0.0348	0.0261
4	0	0
5	0.01356	0.01016
6	0.0056	0.0042
7	0.06332	0.04749
8	0	0
9	0.0941	0.07057
10	0	0
11	0.1575	0.11812
12	0	0
13	0.03517	0.03517
14	0	0
15	0.08405	0.08405
16	0.01725	0.01725

17	0.0075	0.005625
18	0.01383	0.09652
19	0.05555	0.041482
20	0	0
21	0	0
22	0.0663	0.04965
23	0	0
24	0.26795	0.196462
25	0.01885	0.01413
26	0.048456	0.036335

APPENDIX III (Bus Number and Corresponding Names)

Bus Number	Bus Name
1	New Heaven TCN 1
2	Government House 1
3	Loma Linda injection S/S
4	Government House II
5	Amechi Uwani injection S/S
6	Emene Industrial
7	Emene injection S/S
8	New NNPC
9	Trans-Ekulu injection S/S
10	Independence Layout I
11	Independence injection S/S
12	Independence Layout II
13	New Heaven injection S/S
14	Ituku Ozalla
15	Gariki injection S/S
16	New Heaven TCN II
17	Thinker’s corner
18	Thinker’s corner injection S/S
19	Nike Lake injection S/S
20	New Heaven TCN III
21	Kingsway
22	Ebeano injection S/S
23	New Heaven TCN IV
24	Kingsway injection S/S
25	Ninth Mile
26	Ninth Mile S/S