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OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION FOR POWER LOSS MINIMIZATION IN RADIAL DISTRIBUTION NETWORK

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ABSTRACT :

Traditional power grids rely on central generation units, which often cause high losses in distribution networks. To address this, locating and sizing distributed generation (DG) units optimally is crucial for reducing power loss. However, improper placement of DGs can introduce problems such as voltage instability and reverse power flow if not handled carefully. Many existing DG placement methods also face issues like premature convergence and computational complexity. In this study, we introduce a nonlinear optimization approach to determine the optimal DG locations with the aim of minimizing active power loss and operational cost. Our method was implemented using the General Algebraic Modeling System (GAMS) with the IPOPT solver. We tested it on a 26-bus Enugu distribution network. The results show that without any DGs the total power loss is 9.61 MW, whereas with four optimally placed DGs (at the Garki, Kingsway, Ninth Mile, and Trans-Ekulu buses) the loss drops to 2.1MW. This represents a 75% reduction in losses and also yields improved voltage profiles and lower operating costs.

Keywords: Distributed generation, distribution network, optimal placement

1. Introduction

Power distribution networks often have a radial structure with long feeder lines, which makes them susceptible to large resistive losses. Traditional systems rely on a few centralized power plants located far from consumers, further increasing these transmission losses. By contrast, placing distributed generation (DG) units, such as solar or wind generators, closer to load centers can cut these losses, improve voltage profiles, and boost system reliability. However, improper placement or sizing of DGs can introduce problems like reverse power flow or voltage nstability, and may even increase losses if not done carefully.

Research has shown that distant power plants increase losses and may exceed voltage limits when power travels long distances. These challenges have driven interest in DG as a local solution for medium- and low voltage systems. DG units inject active and reactive power closer to the loads, improving service quality. At the same time, DG integration changes the behavior of the grid, so its benefits depend heavily on choosing the right locations and sizes.

Many researchers have studied methods for siting and sizing DG units. For example, Kaur et al. (2014) introduced strategies to reduce losses through optimal DG placement, and Ghosh and Ghoshal (2010) developed a method using iterative search combined with the Newton–Raphson power flow. Manikanta et al. (2016) applied an adaptive quantum-inspired evolutionary algorithm for DG location and sizing, while Babu and Singh (2016) formulated a multi-objective optimization in GAMS. Prabha and Jayabarathi (2016) proposed an invasive weed optimization algorithm, and Jamil and Anees (2016) derived analytical formulas for placing solar PV generators. Das and Mukherjee (2016) also focused on reducing losses and improving voltage profiles in the network.

Many of the existing approaches simplify the problem by fixing either the number or size of DG units in advance, which can limit finding the true optimal solution. The method we propose here removes this restriction: the optimization freely searches over all possible numbers, locations, and capacities of DGs to find the combination that minimizes real power losses in the system.

2.0 Methodology

The goal of our optimization is to minimize the total operational cost of generation while reducing power losses in the distribution network. We formulate an objective function with two parts: one for the cost of power from the substation (conventional generator) and another for the cost of power from the renewable

DG sources. The optimization then chooses DG placements and sizes to minimize this combined cost, which corresponds to reducing active power losses as well.

In setting up this problem, we include constraints to ensure proper operation of the network. Kirchhoff's laws enforce that active and reactive power balance at each bus (node). Standard power flow equations are used to calculate real and reactive power on each line. Inequality constraints impose the generation limits: they cap the output of the substation generators and the DG units based on their capacities. There are also constraints on each line's power flow to keep it below safety limits. Finally, we constrain the voltage magnitude and phase angle at every bus to lie within acceptable ranges. These constraints guarantee the network operates safely while optimizing DG placement.

To model power losses, we use the standard formula for branch power loss under peak load. Specifically, the total power loss PL is given by the sum of losses over all branches, which depends on bus voltages and line conductances. Based on this loss calculation, we then apply the following procedure to place DG units:

1. **Compute base-case losses:** Run a base-case load flow of the network (with no DG) to compute the power loss at each bus under peak load.
2. **Rank buses by loss:** Order the buses in descending order of their active power losses.
3. **Place DG units:** Starting with the bus that has the highest loss, place DG units on the top-loss buses to best reduce losses.

Using this process, the optimization identifies candidate buses for DG installation. The entire model (objective plus constraints) is implemented in GAMS and solved using the IPOPT nonlinear solver.

2.1 Objective Function

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

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

The objective function is made up of two parts: the first part represents the cost function for power derived from sub-station/conventional generator. The second part is the cost function for power supply from the renewable energy source.

2.1.1. Equality Constraints

The equality constraints

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

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

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

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

$$\theta_{ij} = \tan^{-1}\frac{X}{R} \quad (6)$$

$$Z_{ij} = \sqrt{X^2 + R^2} \quad (7)$$

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

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad (8)$$
$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \quad (9)$$
$$P_{dgi}^{\min} \le P_{dgi} \le P_{dgi}^{\max} \quad (10)$$
$$Q_{dgi}^{\min} \le Q_{dgi} \le Q_{dgi}^{\max} \quad (11)$$
$$P_{ij} \le P_{ij}^{\max} \quad (12)$$
$$Q_{ij} \le Q_{ij}^{\max} \quad (13)$$
$$V_i^{\min} \le V_i \le V_i^{\max} \quad (14)$$
$$\delta_i^{\min} \le \delta_i \le \delta_i^{\max} \quad (15)$$

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 is 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.

2.3 Case Study

To test our proposed method, we applied it to a real distribution network: a 26-bus, 33/11 kV system in Enugu, Nigeria. The network topology and line data are described in the paper's appendices. Briefly, the network consists of four independent feeders supplied from a 330/132 kV New Heaven substation. Two of these feeders are served by 60 MVA (132/33 kV) transformers: one feeding Government House, Achara Layout, Emene, Trans-Ekulu, Independence Layout, and New NNPC areas; the other feeding Ituku Ozalla, Thinker's Corner, and Nike Lake. The remaining two feeders each use a 30 MVA (132/33 kV) transformer. One of the 30 MVA transformers serves Kingsway I and Ebeano loads, and the other serves Kingsway II and Ninth Mile.

We implement the optimization as a nonlinear programming problem and solve it using GAMS with the IPOPT solver on a standard computer (Intel Core i7 CPU, 16 GB RAM). This setup allows us to find the optimal DG placements and sizes given the network constraints described above.

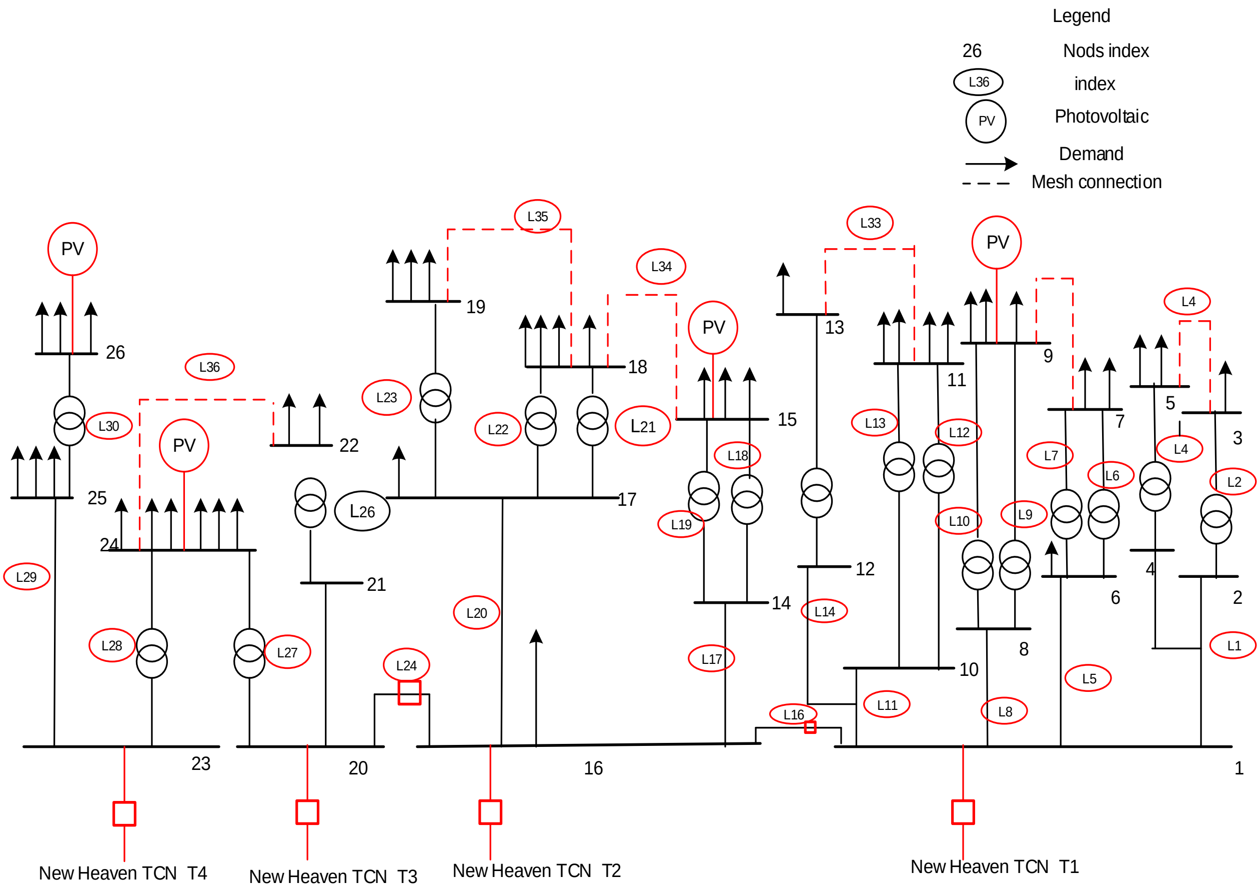

Figure 1: 26-bus Enugu Distribution Network with candidate PVs

3.0 Results and Discussions

3.1. DG Placement:

Using the procedure described, we first determined the best buses to place DGs by identifying the nodes with the highest losses. In the 26-bus network, we consider each of the four sub-networks (each fed by its own transformer). The optimal DG placements (as more units are added) were found to be: -

1 DG: placed at Gariki bus. - **2 DGs:** placed at Gariki and Kingsway Injection Substation. - **3 DGs:** placed at Gariki, Kingsway Injection Substation, and Ninth Mile. - **4 DGs:** placed at Gariki, Kingsway Injection Substation, Ninth Mile, and Trans-Ekulu Injection Substation.

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)	9.6	5.7	4.3	3.7	2.1
Cost of Operation (₦/MW)	1171.2	1083.42	1032.54	977.13	910.14

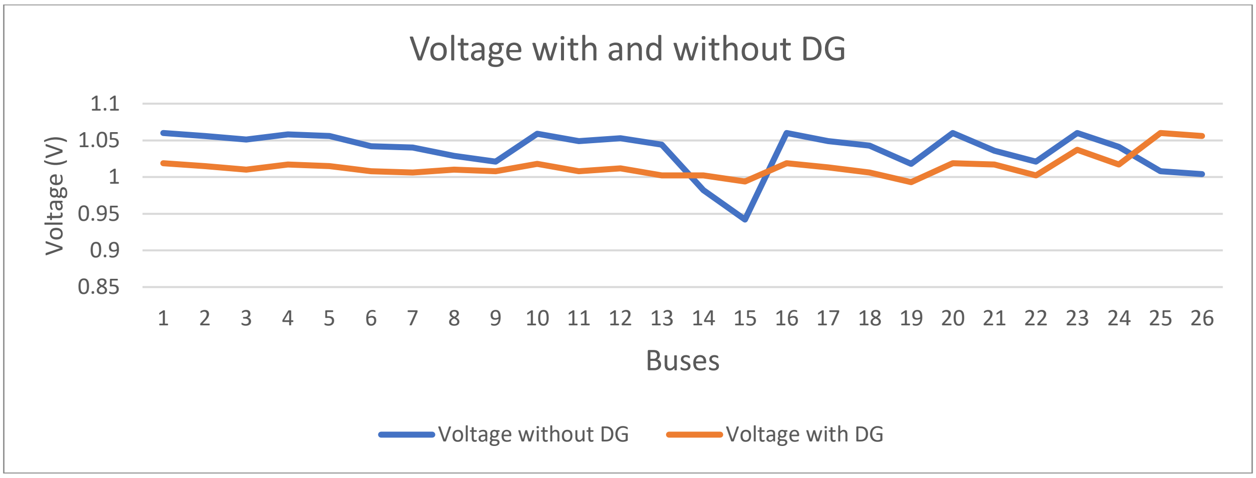

Fig 2: Voltage Profile with and without DG

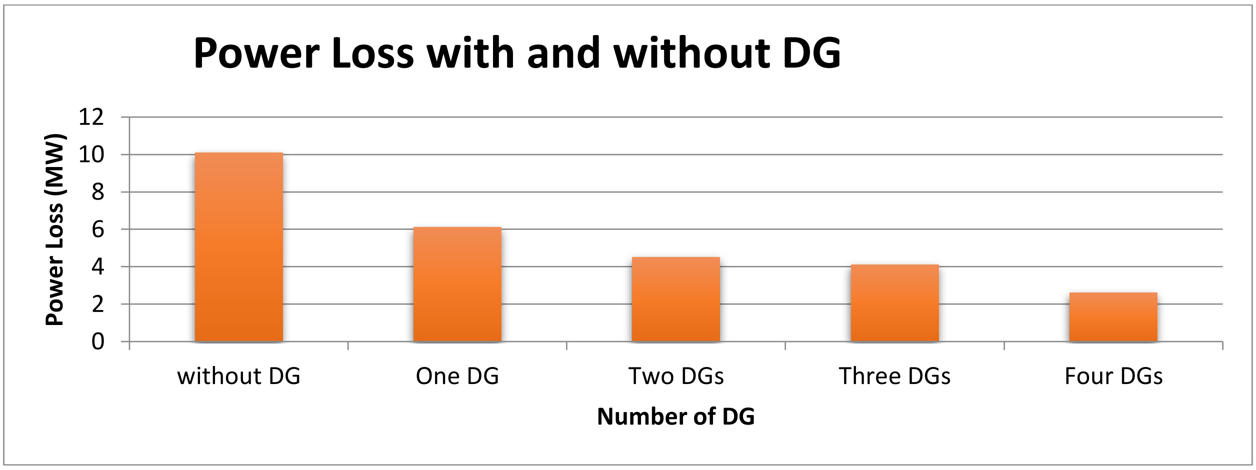

Fig 3: Power loss with and without DG

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. Also there is better power loss reduction when

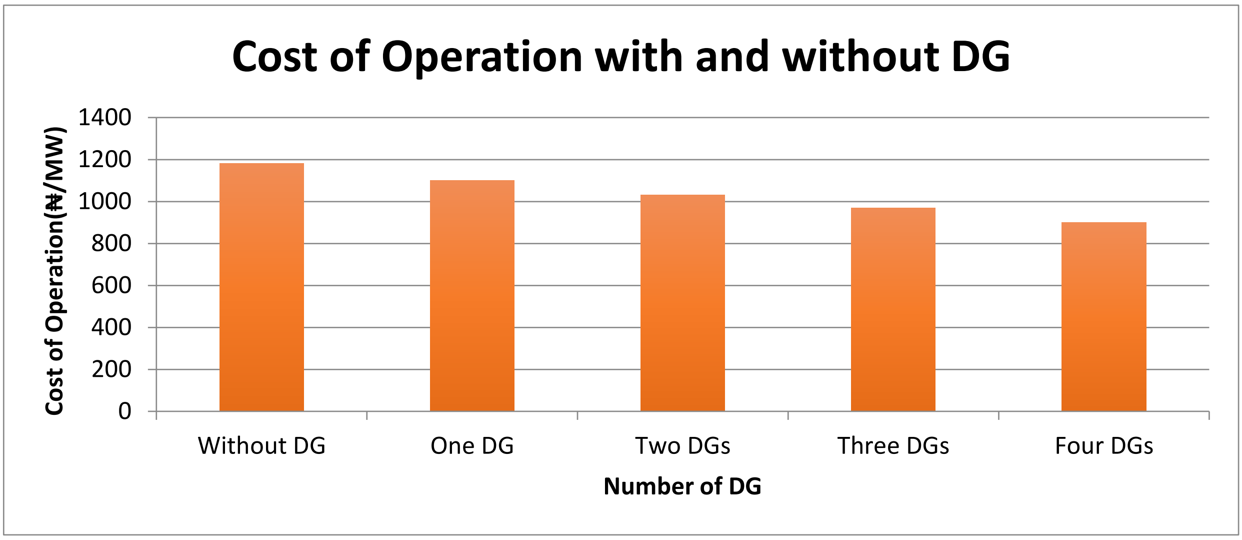

Fig 4: Operation cost with and without DG

These results show a clear trend: adding more optimally placed DGs continually reduces system losses and operating cost. For example, introducing four DGs lowers the loss by about 75% relative to the no-DG case (from 9.6 MW down to 2.1 MW). The voltage profile of the network also improves significantly when DGs are present. With DGs supplying power close to the loads, voltages at buses are higher and more uniform compared to the base case. Moreover, the operating cost drops because the low-cost DG units rather than the more expensive central generator meet a larger share of demand. In summary, the inclusion of DGs at the optimal locations yields substantial benefits: the voltage profile becomes much better than in the no-DG scenario, power losses fall dramatically, and the total generation cost is reduced. These improvements confirm that optimally placed DGs enhance the performance and efficiency of the distribution network.

4.0. Conclusion

Proper placement of distributed generation units in a power distribution system can greatly reduce total real and reactive losses and improve the voltage profile. In this work, we presented a nonlinear optimization method to determine the best locations and sizes of DGs for minimizing system losses. By applying this method to a 26-bus Enugu distribution network using GAMS, we found that optimally sited DGs led to a large drop in losses and a marked improvement in voltage stability. Specifically, adding four DGs reduced the total power loss by about 75%. The operating cost also declined, since more power was supplied by low-cost DGs instead of the substation generator. These results clearly demonstrate the benefits of integrating DG units: when placed correctly, they significantly enhance network efficiency and lower costs compared to the case without DG.

REFERENCES

1. [1] 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.
2. [2] 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.
3. [3] 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
4. [4] 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.
5. [5] 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.
6. [6] 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.
7. [7] 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.

8. [8] 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.
9. [9] 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.
10. [10] 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.
11. [11] 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.
12. [12] Mokryani G. (2015). ‘‘Active distribution networks planning with integration of demand response’’ *Solar Energy* 122 (2015) 1362-1370
13. [13] 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.
14. [14] 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.
15. [15] 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.
16. [16] 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.