AN ANALYTICAL APPROACH FOR OPTIMIZING DISTRIBUTED GENERATORS IN DISTRIBUTION NETWORKS

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The increasing global demand for energy and the decreasing reserves of crude oil are driving the widespread adoption of Distributed Generation (DG) in power applications. Extracting maximum possible benefits from DG placement projects is a challenging task. DG capacities and their locations are factors that highly influence the end results. Therefore, careful consideration is required when placing DGs in distribution networks for loss reduction purposes as the random placement of DGs may result in higher energy losses than the base case losses, resulting in lesser benefits from DG placement projects. Therefore, location and capacity optimization of Distributed Generators should be done in a precise manner.

Mathematically, capacity and location determination of DGs is an optimization problem. Selecting an appropriate optimization methodology is also an extensive concern. Generally, analytical approaches are popular as the simplest and fastest DG placement optimization methodologies. Moreover, some of the analytical approaches yield better results with higher loss reduction percentages when compared with the other available methodologies. Therefore, the aim of this study is to develop an analytical approach to optimize DG capacity and location while yielding higher loss reduction percentages.

This study integrated an Exact Loss Formula-based analytical approach to optimize DG sizing and placement in a 14-bus network. Simulation results indicated that the active power loss in the considered bus network was reduced to 166.18 kW, representing an approximately 77% reduction from the initial losses. These results demonstrate that it is possible to achieve a higher loss reduction percentage using the proposed Exact Loss Formula-based algorithm. However, the current algorithm only addresses power loss minimization and cannot incorporate additional objectives and constraints. Therefore, the proposed algorithm could be further improved by integrating additional objectives and constraints, potentially in combination with other optimization methodologies.

Keywords: Distributed Generation, Analytical Approaches, Exact Loss Formula

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INTRODUCTION

In recent years, with the penetration of distributed generation, many of the distribution networks acquired active characteristics when compared with passive conventional distribution systems. This active nature yields higher network loss reduction capability and significant voltage profile enhancement than the conventional loss reduction techniques such as reactive power injection and network reconfiguration. However, extracting maximum possible benefits from DG placement projects would be a challenging task. DG Capacities and their locations are the factors that highly influence the end results. Therefore, careful consideration is required when placing DGs in distribution networks for loss reduction purposes as random placement of DGs may result in higher energy losses than the base case losses, resulting in lesser benefits from DG placement projects. Therefore, location and capacity optimization of Distributed Generators should be done in a precise manner (Kalambe et al., 2013 and, Prakash et al., 2021).

Mathematically, capacity and location determination of DGs is an optimization problem. Selecting an appropriate optimization methodology is also an extensive concern. Generally, analytical approaches are popular as the simplest and fastest DG placement optimization methodologies. Moreover, some of the analytical approaches yield better results with higher loss reduction percentages when compared to other available methodologies that are available. Therefore, several researchers adopted these methodologies to place Distributed Generators while minimizing distribution losses. However, there are limitations associated with these techniques such as inapplicability to the systems with uniform load distributions and limitations to add more objectives and constraints.

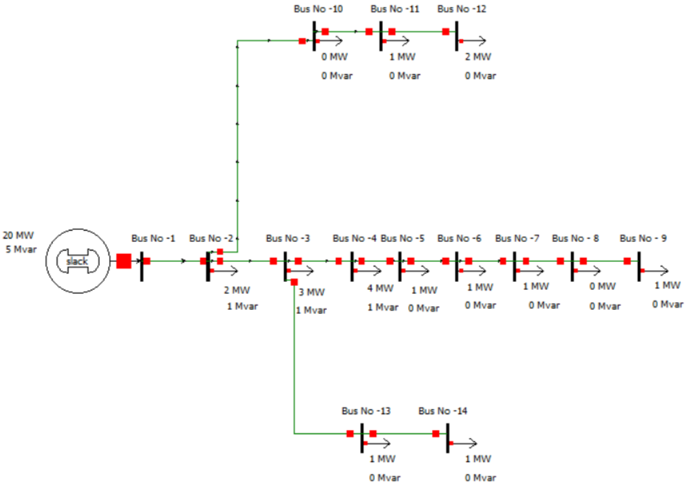
With respect to the power system planning point of view, it is required to consider a higher number of objectives and constraints to getthe maximum benefits from the DG placement projects. When the number of objectives and constraints are high, the objective problem become more complex and advanced optimization methodologies should be adopted. Therefore, various iterative approaches are used in existing research to optimize DG placement while integrating several objectives and constraints. However, the convergence probability and accuracy level of the results are not reasonable. A few researchers have tried to incorporate artificial intelligence-based techniques to optimize the size and capacity of Distributed Generators. However, still the loss reduction percentages are not very competitive, and the adaptability of proposed methodologies is less due to the complex nature of the optimization techniques (Kalambe et al., 2013 and, Prakash et al., 2021). Therefore, the aim of this study is to develop an analytical approach to optimize the DG capacity and location while yielding higher loss reduction percentages.

METHODOLOGY

Initially, a comprehensive literary review on distributed generator (DG) placement in distribution networks was conducted to evaluate the advantages and disadvantages of the existing DG placement research. Then the most significant objective that directly affects the optimization of DG placement was identified based on existing research. As per the research available, the most influential factor on the effectiveness of DG placement projects is Power

Loss. Therefore, active power loss minimization was considered as the sole objective of this research.

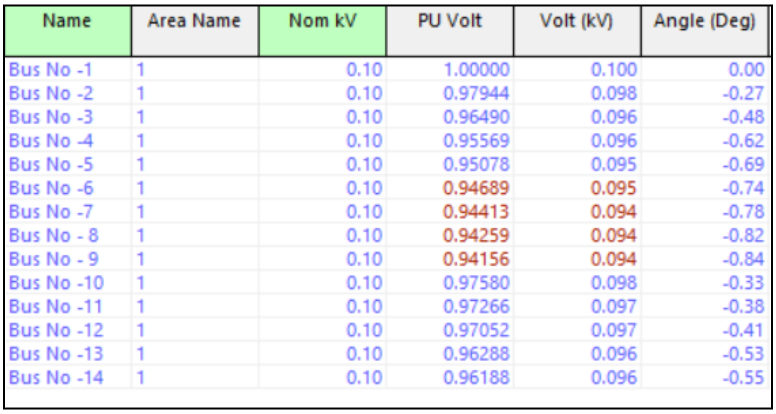
As the first step of the optimization process, a mathematical model was developed using the exact loss formula to determine the optimal capacity and location for DGs. The exact loss formula represents the total power loss of the considered power system. While differentiating the exact loss formula in terms of the capacity of distributed generator which is going to be installed, the DG capacity which yields minimum power losses can be calculated. This technique was used to calculate the best DG capacity in this research considering all the available buses of the considered power system. A fourteen-bus network used as a model power system and that power system was modelled under power world simulator interface. That developed bus network model and bus network data is shown in the figure below,



Bus Number	Active Power (kW)	Reactive Power (kVAr)
2	2000	1000
3	3000	900
4	4000	900
5	1000	100
6	1000	300
7	1000	500
8	500	0
9	1000	100
10	500	100
11	1000	100
12	2000	500
13	1000	100
14	1000	100

Figure 01: Developed Bus Network Model and Load Data

Once the bus network model is developed under the power world simulator, a base case load flow analysis was performed to gather the other necessary data, such as voltage magnitudes, angles, and power losses. Here, the nominal voltage of the considered bus system was set as 100V and the allowable voltage deviation limit was considered as 5% from the nominal voltage. Hence, from the base case simulation it was learned that four buses violate the imposed voltage limits as shown in the figure below. In addition to the voltage data, the base case simulation revealed an initial active power loss of 730.27 kW.



Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)
Bus No -1	1	0.10	1.00000	0.100	0.00
Bus No -2	1	0.10	0.97944	0.098	-0.27
Bus No -3	1	0.10	0.96490	0.096	-0.48
Bus No -4	1	0.10	0.95569	0.096	-0.62
Bus No -5	1	0.10	0.95078	0.095	-0.69
Bus No -6	1	0.10	0.94689	0.095	-0.74
Bus No -7	1	0.10	0.94413	0.094	-0.78
Bus No - 8	1	0.10	0.94259	0.094	-0.82
Bus No - 9	1	0.10	0.94156	0.094	-0.84
Bus No -10	1	0.10	0.97580	0.098	-0.33
Bus No -11	1	0.10	0.97266	0.097	-0.38
Bus No -12	1	0.10	0.97052	0.097	-0.41
Bus No -13	1	0.10	0.96288	0.096	-0.53
Bus No -14	1	0.10	0.96188	0.096	-0.55

Figure 02: Base Case Voltage Magnitudes and Angles for Each Bus in the 14 Bus Network

Then an algorithm was developed using the MATLAB platform to obtain the optimal DG capacities for every bus in the considered bus network. This algorithm mainly consists of mathematical expressions which are derived by differentiating exact loss formula as mentioned earlier for calculating best possible DG sizes. The obtained load flow data from the power world simulator was fed to the algorithm initially as it requires base case voltage magnitudes and angles for initiating the DG capacity determination.

Once all the initial data is inserted to the developed algorithm, the DG capacities were calculated cindering each bus in the network and thus the optimum DG location and capacity was determined. A detailed analysis of this phase is provided under the results section.

RESULTS AND DISCUSSIONS

As mentioned earlier, the output of the developed algorithm is the optimum DG capacity which yields minimum power losses. Therefore, the DG capacities were calculated considering all the buses and obtained DG capacity values with respect to the relevant bus number is indicated in the bar chart shown below. For the sake of simulation, the installed DG power factor was assumed as 0.95 for each case.

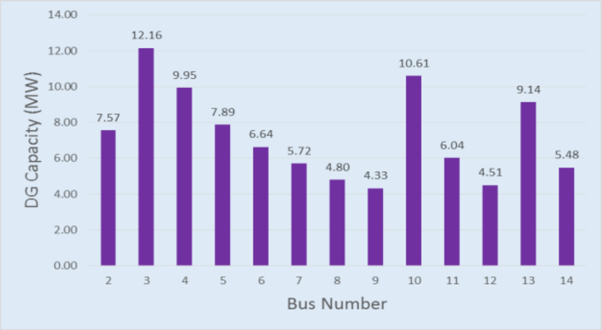


Figure 03: Calculated DG Capacities Which Yields Minimum Active Power Losses

Once the DG capacities were calculated considering all the buses, the previously developed power world simulator model was modified with the installed DGs at the bus location. Then the simulation was carried out again to determine the active power losses after installing the optimum DG for a considered bus location. This process was repeated to calculate power system losses considering DG installation at each bus independently. The power system losses obtained (after installing DGs in each bus) are shown in the figure below.

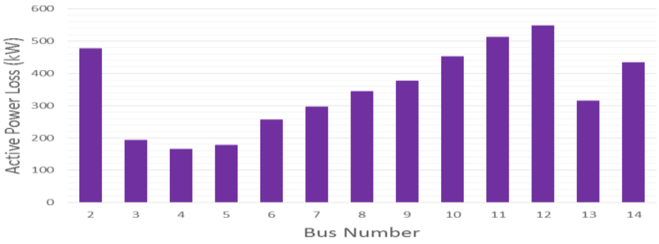


Figure 04: Active Power Losses at Each Bus in 14 Bus Network Following the Installation of Distributed Generators at Each Bus

From the obtained active power losses, it can be clearly seen that the minimum power losses can be obtained when the DG is installed in the fourth bus. In this instance, the power loss is reduced to 166.18kW and it is a significant loss reduction when compared to the intial power loss which is 730.27 kW. In addition to the active power loss minimization, the voltage profile of the considered bus network was also improved. Four voltage violations were recorded previously and after integrating DG into the 04th bus, all the voltage violations disappeared from the system. The voltage profile of the bus network is shown below.

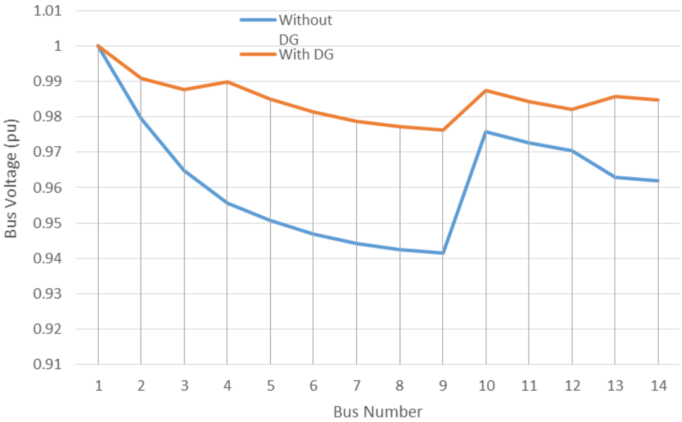


Figure 05: Voltage Profile across the 14-Bus Network, Highlighting the Variations in Voltage throughout the bus Network

CONCLUSIONS/RECOMMENDATIONS

The aim of this research was to develop an analytical approach for optimizing DG capacity and location to achieve higher loss reduction percentages. Existing research on DG optimization methodologies can be broadly divided into Analytical Approaches, Heuristic Approaches, and Artificial Intelligence Approaches. Among these, some analytical approaches yield comparatively better results for DG placement problems when focusing solely on power loss minimization. This study integrated an Exact Loss Formula-based analytical approach to optimize DG sizing and placement in a 14-bus network. Simulation results indicated that the active power loss in the considered bus network was reduced to 166.18 kW, representing an approximately 77% reduction from the initial losses. These results demonstrate that it is possible to achieve a higher loss reduction percentage using the proposed Exact Loss Formula-based algorithm. However, the current algorithm only addresses power loss minimization and cannot incorporate additional objectives and constraints. Therefore, the proposed algorithm could be further improved by integrating additional objectives and constraints, potentially in combination with other optimization methodologies. Moreover, in practical applications, the calculated DG capacities might not be available exactly as determined, so users may need to round up these values when implementing this methodology in practical applications. Additionally, since the load profile used here is an average one, results will be more accurate if the actual load profile is applied.

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