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Assessment of Distribution Generation Integration on Loss Reduction in Distribution Grids

1st Kishan Gadhavi
The Maharaja Sayajirao University of Baroda
Vadodara, India
gadhavikishan1010@gmail.com

2nd Shefail Talati
Electrical Research And Development Association (ERDA)
Vadodara, India
shefail.tatati@erda.org

3rd Ajay Misra
The Maharaja Sayajirao University of Baroda
Vadodara, India
a.p.misra-eed@msubaroda.ac.in

***Abstract*—The strategic location and capacity of distributed generation (DG) units play a crucial role in enhancing their performance in power distribution system. The literature highlights that while DG can contribute significantly to loss reduction, these benefits are maximized only when DG is optimally located and sized. However, utility companies face significant operational challenges due to high penetration of DG. Another major issue that utility companies deal with is that they are unable to grant a DG access to a certain bus that benefits them. For this purpose, the study examines the effects of high DG integration on loss reduction within a distribution network. We are assessing three possibilities for this purpose: (1) a basic case without DG; (2) a demand-based DG strategy that matches DG capacity with load needs; and (3) a loss-optimized DG scenario that uses a Genetic Algorithm (GA) to reduce active and reactive losses for all buses. The radial distribution system is used to examine the efficacy of the three scenarios mentioned above. The evaluated power system is 33- bus radial distribution system, which are benchmark system form literature. For optimal load flow analysis purpose, we used forward-backward sweep method. The encouraging outcome reveals that power loss can be minimized, and the voltage profile has be improved when the DG rating matches the bus's active demand. Integration results in declining returns or negative impacts, including greater losses, especially in distribution networks, when the DG rating is higher than the bus's active demand.**

Keywords— Distributed Generation (DG), Distribution Networks, Power Loss Reduction, Genetic Algorithm

I. INTRODUCTION

The increasing adoption of Distributed Generation (DG) has been a transformative force in the evolution of modern power distribution networks. DG's potential to reduce active and reactive power losses, enhance voltage profiles, and improve system reliability has spurred widespread interest and investment in renewable-based grid integration. However, integrating PV systems into distribution networks presents challenges, as utility companies often must grant DG access to all customers without the ability to restrict access based on the impact on grid losses. This constraint, imposed by regulatory policies, complicates the ability of utilities to optimize grid performance and minimize losses, as DG installations may have either beneficial or detrimental impacts on grid efficiency, depending on their placement and sizing.[1]

Prior research extensively covers the technical and non-technical challenges of DG integration. A significant body of literature focuses on the potential for optimally placed and sized DG to reduce losses. Analytical and optimization-based approaches, such as genetic algorithms and particle swarm optimization, have demonstrated that strategic DG deployment can yield substantial improvements in grid efficiency.[2]Studies have shown that optimal DG allocation can minimize both power losses and overall investment costs, highlighting the importance of location-specific and load-sensitive approaches [3]. Additionally, research indicates that effective control strategies are essential to prevent technical losses from increasing, particularly in networks with high DG penetration and time-varying loads [1].

The inability of utility companies to selectively allocate DG complicates these optimization efforts. Because utility companies must provide DG access to all customers, they cannot fully realize the potential of DG as a tool for targeted loss reduction. In practical terms, this means that utilities may face conditions in which DG installations lead to adverse effects, such as increased losses, voltage imbalances, or over-voltage situations, particularly in radial feeders where reverse power flows and sensitivity to load changes are prevalent [4]. In systems without coordination, unregulated DG penetration may result in situations where additional DG insertion diminishes the effectiveness of loss reduction strategies, as excess DG can increase system losses under certain conditions [5].

The influence of DG is examined in this study. In three distinct scenarios: (1) a basic case without DG; (2) a demand-based DG strategy that matches DG capacity with load needs; and (3) a loss-optimized DG scenario that uses a genetic algorithm to reduce losses for all buses, utilizing the Forward-Backward Sweep technique with the IEEE 33-bus radial distribution network. The outcome of the study demonstrate that although DG can considerably lower losses, this effect is heavily reliant on proper placement and size. It is difficult to achieve consistent loss reduction in an unlimited access situation when utilities are unable to restrict DG access depending on the impact on the distribution network. Excessive DG deployment, especially in high-penetration areas, may lead to a reversal in loss benefits, highlighting the complex interplay between DG placement, capacity, and network topology [6].

II. LOAD FLOW OF POWER DISTRIBUTION NETWORK

A load flow study is an essential component of any electrical distribution or transmission system evaluation. Load flow analysis may be used to calculate the real and reactive power flow across each branch, the voltage magnitude and power angle at each bus or node, and the system's overall real and reactive power losses. Applications such as economic dispatch, state estimate, and security analysis depend on these specifics.

In load flow analysis of the power transmission system, the Newton-Raphson, Gauss-Seidel, and FDLF methods are widely used. However, because the power transmission and distribution systems have distinct characteristics, using the aforementioned methods may cause convergence issues. These techniques are ineffective because the distribution system's R/X ratio is higher than that of the transmission system, which keeps the distribution system in poor condition [7].

There are many different approaches and strategies that may be employed in distribution load flow, but the backward forward sweeping method is the most effective and widely used. This approach calculates the real and reactive power flow from the receiving end node to the sending end node assuming a flat voltage start for the system. It is called the backward forward sweep technique because, after power flow is determined, voltage and angle are computed using those values from sending end node to receiving end node. The new power flow is then determined using these adjusted voltage and angle values, and the process continues until convergence is reached.

A less amount of computer memory is required for this procedure, and all that is required is the assessment of straightforward algebraic equations pertaining to voltage. One major benefit of this approach over others is that it does not involve the calculation of trigonometric terms.[8].

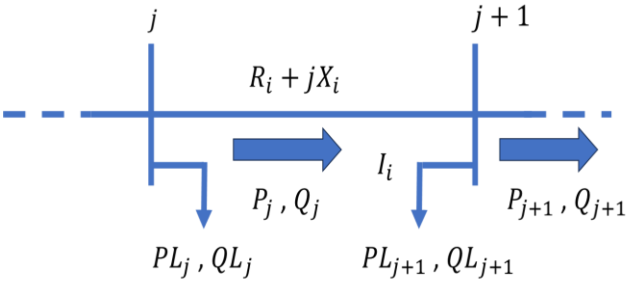

Fig. 1. Illustration of a distribution line with two busses

Any two buses in a distribution network may be represented like in Figure 1, and the terms are as follows:

I_i = Current passes through the branch i,

j = Sending end node of branch i,

$j+1$ = Receiving end node of branch i,

R_i = Resistance of branch i,

X_i = Reactance of branch i,

PL_j, PL_{j+1} = Real power load connected at node j and j+1 respectively

QL_j, QL_{j+1} = Reactive power load connected at node j and j+1 respectively

P_j , Q_j = Effective Real and Reactive power flow from node j

P_{j+1} , Q_{j+1}= Effective Real and Reactive power flow from node j+1

From the above generalized data, we can obtain the formulas for voltage magnitude, voltage angle, active and reactive power flow, and active and reactive power loss as[8].

$$P_j = [P_{j+1} + P_{Lj+1}] + r_i \frac{[P_{j+1}+P_{Lj+1}]^2 + [Q_{j+1}+Q_{Lj+1}]^2}{[V_{j+1}]^2} \tag{1}$$

$$Q_j = [Q_{j+1} + Q_{Lj+1}] + x_i \frac{[P_{j+1}+P_{Lj+1}]^2 + [Q_{j+1}+Q_{Lj+1}]^2}{[V_{j+1}]^2} \tag{2}$$

$$V_{j+1} = \sqrt{[V_j]^2 + 2(P_j r_i + Q_j x_i) + ((r_i)^2 + (x_i)^2)\frac{(P_j)^2+(Q_j)^2}{(V_j)^2}} \tag{3}$$

$$\delta_{j+1} = \delta_j + \tan^{-1}\frac{(Q_j r_i + P_j x_i)}{(V_j)^2 - (P_j r_i + Q_j x_i)} \tag{4}$$

It is necessary to know the nearby nodes and adjacent branches of every node as well as each receiving end node of the system in order to use the load flow using backward forward sweep approach. From these data, the forward propagation path—that is, the path from the source node to each receiving end node—and the backward propagation path—that is, the system elements that must be calculated from each end node to the sending end node—are listed. A number of iterations are then determined based on the convergence criteria, which ultimately provides the load flow analysis of any power distribution system[9].

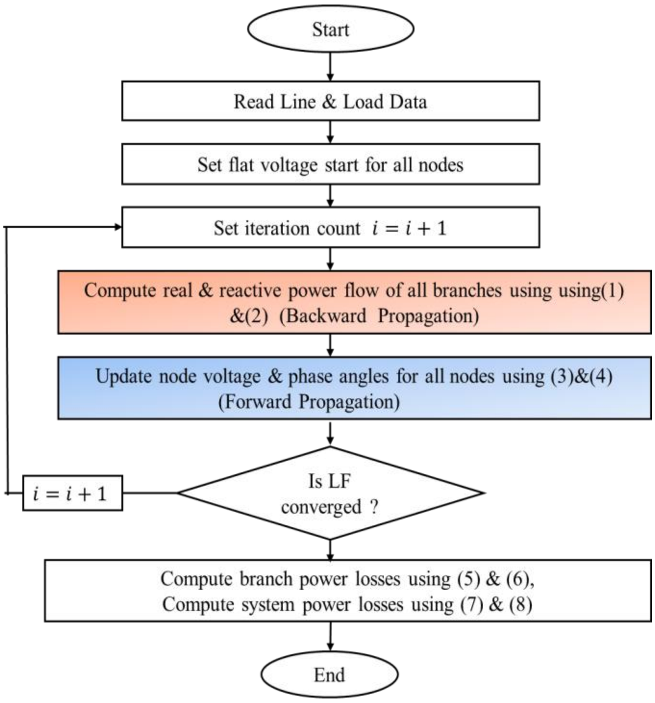

Fig. 2. Flow chart of backward forward sweep distribution load flow method

The backward forward sweep distribution load flow technique flow chart is displayed in Figure 2. Any branch's active and reactive power loss may be computed as[8],

$$P_{loss}(i) = R_i \frac{(P_j^2 + Q_j^2)}{V_j^2} \tag{5}$$

$$Q_{loss}(i) = X_i \frac{(P_j^2 + Q_j^2)}{V_j^2} \tag{6}$$

$$\text{Toal active power losses } = \sum_{j,i}^{n,b} R_i \frac{(P_j^2 + Q_j^2)}{V_j^2} \tag{7}$$

$$\text{Total reactive power losses} = \sum_{j,i}^{n,b} X_i \frac{(P_j^2 + Q_j^2)}{V_j^2} \tag{8}$$

Equation no (7) and (8) are give Total active and reactive power losses in system.

III. PROPOSED GENETIC ALGORITHM FOR FINDING OPTIMAL RATING OF DG FOR ALL BUS

DG's ideal rating is crucial since a lower rating could not offer the necessary advantages. When compared to other optimization techniques, the genetic algorithm is regarded as one of the most potent techniques. Natural selection is the foundation of the suggested method for DG placement. Simply knowing the fundamentals of genetics will enable you to construct a genetic algorithm with ease. In general, the system with the fewest losses is regarded as the fittest one; thus, the primary criterion for DG's optimum rating is loss reduction[10]. The optimum genetic algorithm for DG's best rating may be developed by taking losses into account as the objective function. The following fundamental processes are often involved in genetic algorithms:

- Selection: The goal function is used to choose the buses in this stage. Losses are typically regarded as the objective function.
- Crossover: The chosen busses will be go through crossover, which is the process of creating a new population by treating the chosen population as their parents.
- Mutation: The created offspring undergoes a dramatic alteration as a result of this procedure. A new generation is created shortly after mutation is put into practice.

The optimal outcome is provided by this new generation.

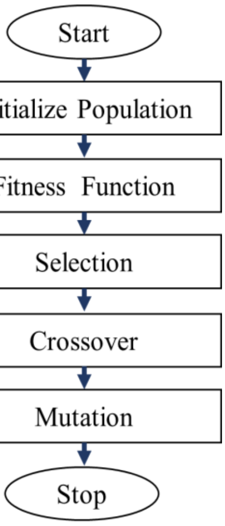

Fig. 3. Proposed Genetic Algorithm Functional flowcharts

The algorithm for proposed Genetic Algorithm optimization method is as follows. The population is initialized at the start of the procedure, creating a collection of possible solutions (chromosomes). The efficiency of each chromosome in resolving the issue is then assessed using the objective function. The fittest chromosomes, which reflect the best solutions in the current population, are determined by calculating the fitness function based on these assessments. Chromosomes are then chosen for crossover based on a predetermined crossover rate. These chosen chromosomes are subsequently subjected to the crossover process, which combines genetic material from parent chromosomes to create new kids. Lastly, to provide genetic variety and avoid premature convergence, mutation is applied to certain chromosomes at a predetermined mutation rate, improving the search process overall.

A genetic algorithm is constructed for the purpose of minimizing losses by using equation (9) as its objective function.

$$Min.f = \sum_{i=1}^{I_i} (I_i^2)\, R_i \qquad (9)$$

Were

I_i =Current at i^{th} branch

R_i = Resistance at i^{th} branch

I= Total number of available branches

i = Branch number

The Functional flowcharts of proposed Genetic Algorithm is shown in Figure 3.

Constant load modelling, as described in equation (10), can provide advantages including safety, lower energy use, and economic stability. Using this formula, the real power losses at any bus where DG is updated

$$P_{new\,,j} = P_{load,j} - P_{DG,j} \qquad (10)$$

The systems were tested using the following working parameters of proposed genetic algorithm.

1. Crossover Rate = 0.850
2. Mutation Rate = 0.030

IV. METHODOLOGY

This study employs a structured approach to assess the effects of Distributed Generation (DG) on loss reduction within a radial distribution network.

The methodology involves modelling the IEEE 33-bus system and analysing three scenarios: no DG, demand-based DG, and loss-optimized DG using genetic algorithm. To capture realistic operational conditions, the Forward-Backward Sweep method is used for load flow analysis. This section outlines the technical setup, data acquisition, scenario design, load flow analysis, and evaluation criteria.

The IEEE 33-bus radial distribution system is selected due to its relevance in evaluating the impacts of DG in radial configurations, common in distribution networks. The network parameters, such as line impedances and bus loads are modelled using data derived from IEEE standards.

To explore different configurations of DG, the study considers three cases:

A. Case 1: No DG (Baseline)

This case represents the system operating without any DG. It serves as a baseline to assess the distribution losses and voltage profiles under typical load conditions. The load flow analysis is conducted to calculate initial line and bus losses, voltage drops, and other parameters across the IEEE 33-bus network.

B. Case 2: Demand-Based DG

In this case, DG generation is introduced with capacity aligned to meet the specific demand of each bus. The DG size is selected to partially or fully offset the load at each bus, reducing the dependency on the upstream grid. This approach aims to evaluate DG insertion to localized demand affects overall system losses and voltage profiles.

C. *Case 3: Loss-Optimized DG using genetic algorithm*

In this instance, DG generation's rating is optimized to reduce overall system losses for every bus. The configuration with the lowest losses has its DG rating modified repeatedly during the optimization process. To guarantee realistic implementation, loss optimization takes into account the limitations of power flow stability and bus voltage restrictions. The DG rating, which was optimized using the genetic algorithm, is shown in Table 1.

TABLE I. OPTIMIZED DG RATING

Bus number	**Optimized dg rating using genetic algorithm in (kW)**	**Bus number**	**Optimized dg rating using genetic algorithm in (kW)**
2	115	18	103
3	103	19	103
4	138	20	103
5	69	21	103
6	69	22	103
7	230	23	103
8	230	24	483
9	69	25	483
10	69	26	69
11	51	27	69
12	69	28	69
13	69	29	138
14	138	30	230
15	69	31	172
16	69	32	241
17	69	33	69

V. SIMULATION RESULTS & DISCUSSION

The study is carried out and examined on an 11 kV radial distribution system using an IEEE 33 bus. In MATLAB R2023a software, a program is created. For load flow analysis we using the forward-backward techniques and finding optimal rating fo DG for all bus we used proposed Genetic Algorithm as an optimization technic.

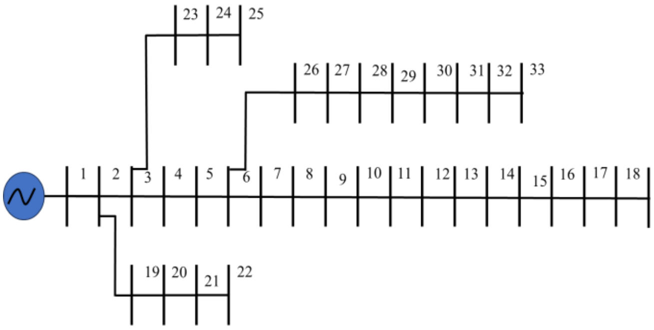

Fig. 4. 33 Bus Radial Distribution Test System.

A 33-bus radial distribution test system with 32 branches and a single feeder with four laterals is shown in Figure 4. Reactive power demand is 2300 kVAR, while total active power consumption is 3715 kW. Additionally, we solely employed type-1 DG system injects for active power in this work.

TABLE II. SYSTEM'S RESULTS FOR EACH CASE.

Result	**Active power loss (kW)**	**Reactive power loss (kVAR)**	**Percentage loss reduction in active power loss**	**Percentage loss reduction in reactive power loss**	**V min in (p.u.) at (node)**
Result of No DG	849.471	566.881	-	-	0.8815 (18)
Result of Demand Based DG	240.760	160.823	71.657	71.630	0.9612 (33)
Result of Loss Optimized DG	246.915	164.869	70.93	70.916	0.9714 (33)

Table 2 displays the lowest voltage in p.u. for each scenario, as well as the actual power loss, reactive power loss, and percentage decrease in active and reactive power loss from the base case. In the absence of DG, the active and reactive power losses are 849.47 kW and 566.88 kVAR, respectively, whereas bus number 18 has the lowest bus voltage of 0.8815 p.u.

In Demand Based DG, the active and reactive power losses are 240.76 kW and 160.82 kVAR, respectively, whereas bus number 33 has the lowest bus voltage of 0.9612 p.u. Additionally, the active and reactive power loss reduction percentages were 71.56% and 71.63%, respectively.

In Loss Optimized DG using a genetic algorithm, the active and reactive power losses were 246.91 kW and 164.86 kVAR, respectively. Table 1 shows the DG rating. Bus 33 has the lowest bus voltage, 0.9714 p.u. Additionally, the active and reactive power loss reduction percentages were 70.93% and 70.91%, respectively.

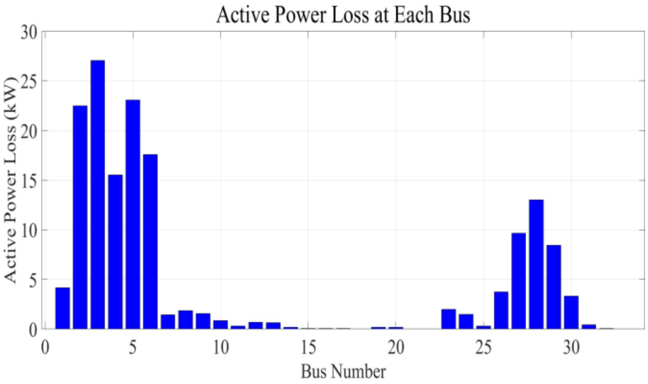

Fig. 5. Active power loss at each bus in case-2

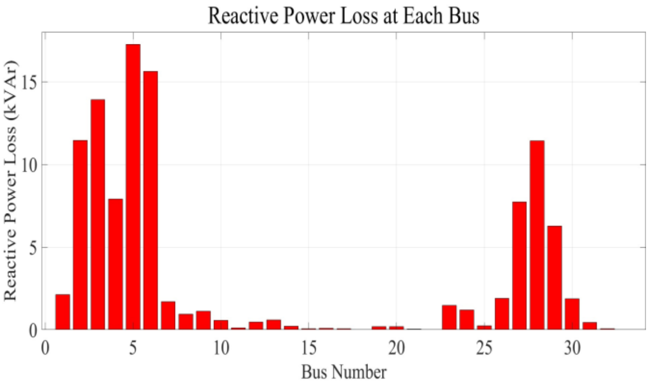

Fig. 6. Reactive power loss at each bus in case-2

For Demand-based DG, active and reactive power loss at every bus is shown in Figure 5 and 6. According to those two figures, end nodes between losses are lower and losses are larger in the vicinity of the substation.

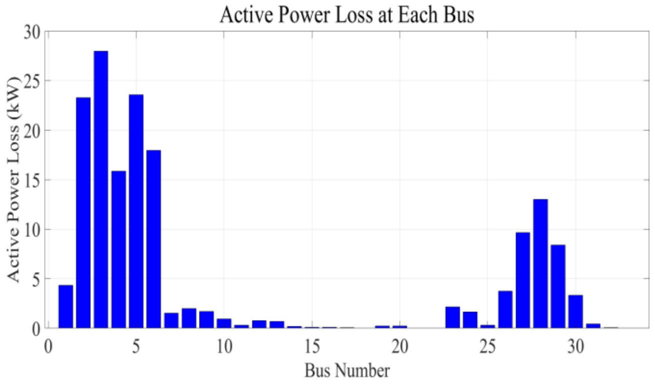

Fig. 7. Active power loss at each bus in case-3

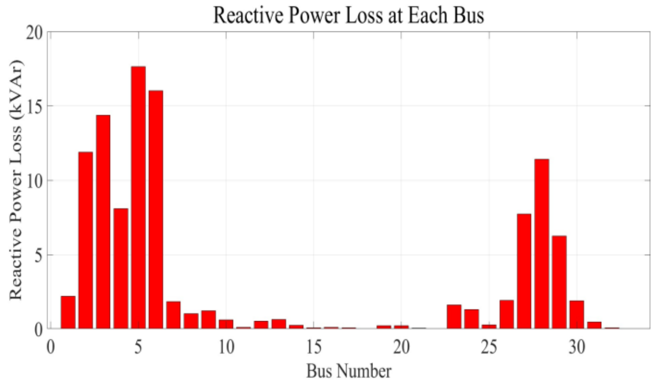

Fig. 8. Reactive power loss at each bus in case-3

Figures 7 and 8 show the active and reactive power loss at each bus for the genetic algorithm-based loss-optimized DG. According to those two figures, end nodes between losses are lower and losses are larger in the vicinity of the substation.

We found that the total active power loss was approximately 71% of the base case, while the reactive power loss was around 71% of the base case . The addition of DG at each bus reduced the line currents by effectively lowering the load at each bus. Furthermore, the voltage profile of the system improved significantly due to the higher level of DG power supplied to each bus.

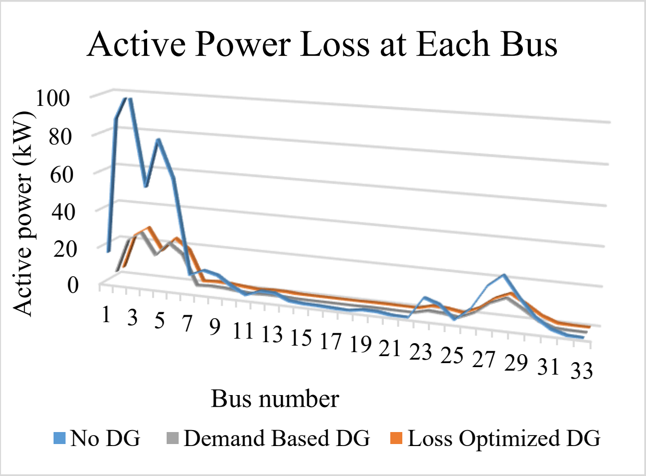

Fig. 9. Active power loss at each bus all case

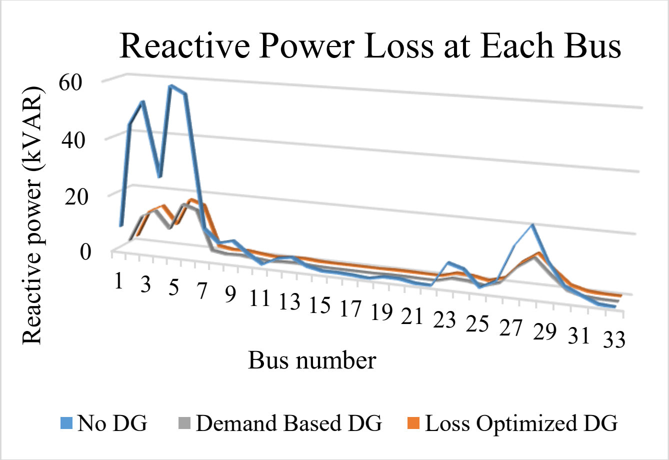

Fig. 10. Reactive power loss at each bus three case

The active and reactive power loss for all three case is illustrated in figure 9 and 10 . it is to be mention active and reactive power loss significantly Redus in Demand based DG and Loss Optimized DG case.

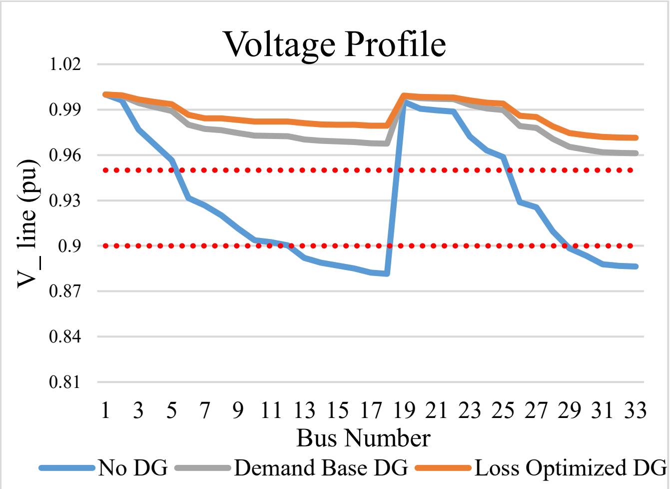

Fig. 11. Bus voltage comparison for all case

Figure 11 shows the p.u. system bus voltage for three different scenarios. It should be noted that the distribution network system has a lower voltage profile when no DG is inserted. In the following image, buses 5 through 18 and 25 through 33 experience below-acceptable voltage levels when there is no DG present in the system. The system voltage profile is greatly enhanced by the use of DG, such as demand basis DG and optimal rating DG employing genetic algorithms.

The demand-based DG rating and the loss-optimization-based DG outcome are found to be equal. in order to ascertain whether utility companies are restricting access to DG. They can provide the bus an equivalent amount of DG rating to the active demand of the bus if a higher DG rating has a detrimental effect on the system, such as increased power loss and reverse voltage.

A comparison of the three scenarios shows that the system has a poor voltage profile and significant losses in the absence of DG. As opposed to the no-DG situation, the second and third scenarios, in which DG is appropriately rated to match bus demand, produced notable improvements in the voltage profile and a decrease in system real and reactive power losses of almost 71%. This demonstrates that DG ratings that match the demand of each bus efficiently reduce power losses, but higher DG ratings result in declining returns and may even have an adverse effect on the system.

VI. CONCLUSION

This paper's work will provide an overview of DG rating identification, power loss computation, determining the minimal power loss, and voltage profile characteristics. when the DG rating differs between demand-based and genetic algorithm-based loss optimization. Real and reactive power loss are reduced, and the system voltage profile improves significantly as the DG rating is determined using a genetic algorithm. Placing the DG on each node between 2 and 33 was the best option when taking power loss into account. The study also demonstrates that while oversizing can result in decreasing returns and higher losses, rating DG optimum based on current demand produces the greatest outcomes. According to these results, utility firms may support a more sustainable and effective energy network by properly designing and integrating DG, which will dramatically reduce power losses, improve grid dependability, and increase voltage stability.

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