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ENHANCEMENT OF VOLTAGE PROFILE AND MINIMIZATION OF LOSS USING INTEGRATED DISTRIBUTED GENERATION

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ABSTRACT

Growing electricity demand and the push for clean energy have led to greater use of distributed generation (DG) in modern distribution systems. This paper investigates the influence of three DG technologies such as diesel engines, wind power, and solar photovoltaic system to improve voltage regulation and minimize losses in the IEEE 33-bus network. The analysis employs MATLAB-based simulations to assess changes in network performance stemming from DG integration. The study applies particle swarm optimization (PSO) to determine the most effective DG with its sizes and locations, Emphasizes that accurately positioned DG units can strengthen voltage stability and minimize system losses. In addition, suboptimal DG placement will result in voltage anomalies and higher losses, reinforcing the importance of careful DG planning within the distribution grids. The results obtained for with DG and without DG enhancement in voltage profile and loss minimization were compared with the existing results and is encouraging. The findings with the successful incorporation of renewable technologies towards improved stability and reliability of grid is very supportive.

I INTRODUCTION

The global energy landscape is undergoing a significant transformation as the demand for electricity continues to rise alongside increasing environmental concerns. Traditional centralized power generation, heavily reliant on fossil fuels, faces growing criticism due to its environmental impact and vulnerability to supply disruptions. This has led to an intensified focus on cleaner, more sustainable energy solutions, with renewable energy sources playing a central role in this transition. Distributed generation (DG) refers to the decentralized production of electricity by small-scale power generation units located close to the point of consumption, rather than at large, centralized power plants. These generation units, often called Distributed Energy Resources (DER). Integrated distributed generation (DG) systems that combine both renewable and non-renewable energy sources play a vital role in enhancing voltage profiles and mitigating power losses in electrical distribution networks. Advanced optimization techniques are often used to determine the best placement and sizing of these hybrid DG units, maximizing their benefits in power loss reduction and voltage profile improvement.

Distributed generation (DG) has emerged as a promising approach to meet these challenges by producing electricity closer to the point of consumption. DG technologies, such as diesel generators, wind turbines, and photovoltaic (PV) solar systems, enable greater flexibility and resilience in power systems. By decentralizing power production, DG can reduce transmission losses, improve voltage profiles, and provide backup power during outages, contributing to a more reliable and efficient grid. Despite these advantages, integrating DG into existing distribution networks introduces technical and operational complexities. Drawbacks of DG integration, such as voltage drop and power losses, which result from the unplanned connection of DG in distribution networks[1]. The intermittent nature of renewable resources like wind and solar, along with the potential for voltage fluctuations and increased power losses, requires careful planning and management. . The goal is to examine how DG location impacts power losses and voltage regulation to achieve maximum benefits[2]. Ensuring that DG units are optimally sized and strategically placed is crucial to maximizing their benefits while minimizing adverse effects on the network. The traditional energy structure, coupled with high DG penetration, seriously impedes the power system. This is due to the DG changing the grid's structure and increasing the randomness of system running [3]. The widespread adoption of Distributed Generation (DG) presents significant integration complexities for distribution networks (DNs). optimal location, configuring protective devices, and managing voltage control and power quality [4].This paper investigates the impact of integrating diesel generators, wind turbines, and PV systems on the voltage profile and power losses of the IEEE 33-bus distribution system. Using Matlab and the extended Newton-Raphson load flow method, the study evaluates the influence of different DG technologies and configurations on system performance. The results offer valuable guidance for utilities and policymakers aiming to enhance grid efficiency and accommodate the growing share of renewable energy sources.

II PROBLEM IDENTIFICATION

Traditional electrical distribution networks are primarily designed for unidirectional power flow from centralized generation plants to end consumers. These systems typically rely on large, centralized generators connected to the transmission grid, with distribution feeders delivering electricity to loads. The voltage regulation and power loss management in such systems are managed through transformers, capacitors, and voltage regulators positioned along the distribution feeders. The IEEE 33-bus system is a classic example used for studying such conventional distribution networks without distributed generation.

However, this centralized system faces challenges as electricity demand grows and renewable energy adoption increases. The network's design lacks flexibility to accommodate bidirectional power flows or variable power injections from distributed generators located near load centers. This limitation affects voltage stability and leads to increased power losses, particularly when loads vary widely or generation is intermittent. The Power loss and voltage profile equation is given below.

For a branch between buses i and j, the real power loss is given by:

$$P_{loss,ij} = R_{ij} \frac{(P_{ij}^2 + Q_{ij}^2)}{|V_i|^2} \qquad 1$$

and the total system real power loss is:

$$P(loss, total) = \sum((i, j) \in branches)\ P(loss, ij) \qquad 2$$

where:

- R_{ij}: Line resistance between bus i and j
- P_{ij}, Q_{ij}: Active and reactive power flow from bus i to j
- $|V_i|$: Voltage magnitude at sending end bus

To evaluate voltage regulation improvement:

- $VDI = 1/n \sum(i = 1)\hat{}n(1 - |V\_i|)$ 3

The increasing integration of distributed generation (DG) sources into electrical distribution networks introduces complex challenges in maintaining voltage stability and minimizing energy losses. While DG can improve system reliability and reduce transmission losses, improper sizing or placement of DG units can cause voltage fluctuations, reverse power flows, and increased losses. This is particularly problematic in distribution networks originally designed for unidirectional power flow, such as the IEEE 33-bus system. Therefore, there is a critical need to thoroughly analyze how different DG technologies—diesel generators, wind turbines, and photovoltaic (PV) systems affect network performance.

Moreover, the intermittent nature of renewable DG sources and varying load demands complicate voltage regulation and loss minimization. Without appropriate analytical tools and methodologies, power system operators face difficulties in optimizing DG integration to balance benefits against operational risks. This study addresses these issues by modeling and simulating DG impacts on voltage profiles and power losses, providing insights to guide better planning and operation of distribution networks. The incorporation of distributed generation (DG) into the power system has significantly expanded, driven by the privatization of electricity markets, increased environmental awareness, and advances in technology. Over the past ten years, numerous researchers have concentrated on addressing the issues caused by the uncoordinated deployment of DG within distribution networks. These networks inherently face challenges such as voltage drops, power losses, elevated fault current levels during short circuits, and complications arising from bidirectional power flow—a sharp contrast to the traditional unidirectional flow of electricity from higher to lower voltage levels. In [5] a genetic optimization algorithm has been used in order to find the optimal location and size of different DG units in a radial distribution system. Three constraints (voltage, active and reactive power losses and DG size) and the Newton-Raphson method have been used in an effort to reduce the total power losses and improve the voltage profile. The goal is to minimize total electricity costs while considering the power output limits of DGs such as photovoltaic and wind turbines. The approach aims to improve the efficiency of DG integration by optimizing the placement and capacity of energy storage, thereby enhancing grid reliability, reducing costs, and better managing the variability of renewable generation[6]. The study concludes that integrating DG units in the distribution network significantly enhances the voltage profile and reduces active power losses. The presence of DG improves system performance, and the Backward Forward Sweep method effectively handles the complexities introduced by DG, making it a preferred choice for accurate load flow analysis in such systems[7].A relatively straightforward analytical approach based on voltage sensitivity index analysis was introduced in to reduce real power losses, improve voltage profiles, and release substation capacity[8]. Another analytical method for determining the optimal size and placement of DG units was presented in. The authors concluded that integrating a single DG unit of optimal size at the best location achieves lower losses and better voltage profiles compared to installing multiple DG units[9].

In [10] utilized particle swarm optimization to minimize overall power losses and enhance the voltage profile in distribution systems incorporating distributed generation. For calculating power losses and node voltages throughout the network, the Newton-Raphson method was employed. Similarly, in [11] particle swarm optimization was applied to the placement of distributed generation units in radial distribution systems, demonstrating reductions in active power losses along with improved voltage profiles.

III PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a nature-inspired, population-based stochastic optimization technique developed by Kennedy and Eberhart (1995) that simulates the social behavior of bird flocking or fish schooling to search for optimal solutions in a multidimensional search space. In PSO, each potential solution, called a particle, adjusts its position and velocity iteratively based on its own best-known position and the global best position found by the entire swarm, thereby balancing exploration and exploitation effectively. Mathematically, the velocity v_i and position x_i of the i-th particle in an n-dimensional space are updated using the following equations 1 and 2:

$$v_i^{t+1} = wv_i^t + c_1r_1(p_i - x_i^t) + c_2r_2(g - x_i^t) \tag{1}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{2}$$

where t denotes the iteration index, w is the inertia weight controlling the impact of the previous velocity, c_1 and c_2 are acceleration coefficients representing the cognitive and social components respectively, r_1 and r_2 are independent random numbers uniformly distributed in the interval , p_i is the personal best position of particle i, and g is the global best position discovered by the swarm. This mechanism enables particles to explore the search space while exploiting the knowledge gained, making PSO an efficient algorithm for a wide range of complex optimization problems without requiring gradient information. Optimizing the placement and sizing of Distributed Generation (DG) units in electrical distribution networks plays a critical role in minimizing power losses and improving voltage profiles. Particle Swarm Optimization (PSO) has been widely employed as an effective metaheuristic algorithm for this purpose due to its simplicity and fast convergence. PSO simulates a swarm of particles where each particle represents a candidate DG placement and sizing solution; these particles iteratively update their positions based on their personal best performance and the global best solution found by the swarm. The objective is to minimize power losses while maintaining system constraints such as voltage limits and generation capacity. Mathematically, the PSO algorithm updates each particle's velocity and position using the following equations 3 and 4:

$$v_i^{t+1} = wv_i^t + c_1r_1(p_i - x_i^t) + c_2r_2(g - x_i^t) \tag{3}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{4}$$

where x_i is the position vector indicating the DG location and size, v_i is the velocity vector, p_i and g are the personal and global best positions respectively, and w, c_1, c_2, r_1, r_2 are the inertia weight, acceleration coefficients, and random factors influencing the particle motion. Studies on real distribution networks have shown that PSO-based DG placement significantly reduces total network power losses and enhances voltage stability, thus validating its effectiveness for practical power system operation and planning. This optimization approach is readily implementable in environments like MATLAB and offers a systematic method for loss reduction in radial distribution systems with DG integration. Studies demonstrate that PSO effectively minimizes power losses, enhances voltage profiles, and improves system stability when applied to DG placement problems. Its adaptability to hybridization with other algorithms, such as genetic algorithms, enhances its capability to achieve near-global optima with improved robustness and solution quality. These characteristics make PSO a highly suitable and reliable choice for modern power system planning challenges involving DG integration.

IV TEST SYSTEM

To evaluate the performance of the proposed methodology, simulations were carried out on the standard IEEE 33-bus radial distribution system, which is widely adopted in literature as a benchmark network for distribution system analysis. To assess the effectiveness of the proposed approach for optimal placement of Distributed Generators (DGs), the standard IEEE 33-bus radial distribution system is employed as the test system. The Distribution system single line diagram and load line data's are given in appendix. This system is widely recognized in the power systems research community due to its moderate size, radial topology, and relevance to real-world urban distribution networks. It is particularly suitable for studies involving power loss minimization and voltage profile enhancement through DG integration. The IEEE 33-bus system comprises 33 buses and 32 distribution branches with a total real and reactive power demand of 3.715 MW and 2.3 MVar, respectively. The network operates at a base voltage of
12.66 kV and a base apparent power of 100 MVA. Bus 1 functions as the slack bus and serves as the source substation feeding the system. The distribution lines are modeled using their respective resistance and reactance values as provided in the standard benchmark data.In its original configuration, the system is radial and unbalanced with significant voltage drops and real power losses, especially in the remote sections of the network. The minimum bus voltage in the base case is typically observed to fall below the permissible limits defined by IEEE standards, which further justifies the need for DG placement to support voltage levels and reduce losses. For this study, DG units are considered as controllable sources capable of

injecting power. The penetration level of DGs, their optimal sizes, and locations are determined using the proposed optimization algorithm with the objective of minimizing total real power loss and improving the overall voltage profile of the network. Constraints such as voltage limits (typically 0.95 to 1.05 p.u.), line flow capacities, and DG capacity bounds are incorporated to ensure practical feasibility. The simulations are performed under steady-state conditions using load flow analysis based on the backward/forward sweep method, which is well-suited for radial distribution systems. Comparative analysis is conducted between the base case (without DGs) and the optimized case (with DG placement), highlighting the improvements in loss reduction and voltage regulation.

V] RESULTS AND DISCUSSION

A) Analysis of Distribution Network Without DG

The distribution network was first analyzed without the integration of any distributed generation units and the single line diagram of IEEE 33 bus system is given in appendix. Power flow studies were performed to determine the baseline voltage profile and power losses within the IEEE 33-bus system. And the standard load and line details are given in Appendix. Under these conditions, it was observed that the voltage magnitude at certain buses fell below acceptable limits, indicating voltage instability, typical of radial distribution systems without local generation. Additionally, the system experienced considerable active power losses, primarily due to long feeder lengths and load concentrations at distal buses.

The Distribution system's total power loss, voltage profile and voltage drop index before the integration of DG is shown in table 5.1

Parameter	**Without DG**
Power Loss (kW)	133.27
Voltage Profile (pu)	0.9029
Voltage Drop Index (VDI)	0.0970

Table: 5.1 Parameters and values before DG

B) Analysis of Distribution Network Simulation With DG

The simulation of the distributed network including the integration of DG's have been performed in MATLAB as shown in Fig 5.1 , resulting in high power loss and reduced voltage profile as shown in Table 5.2

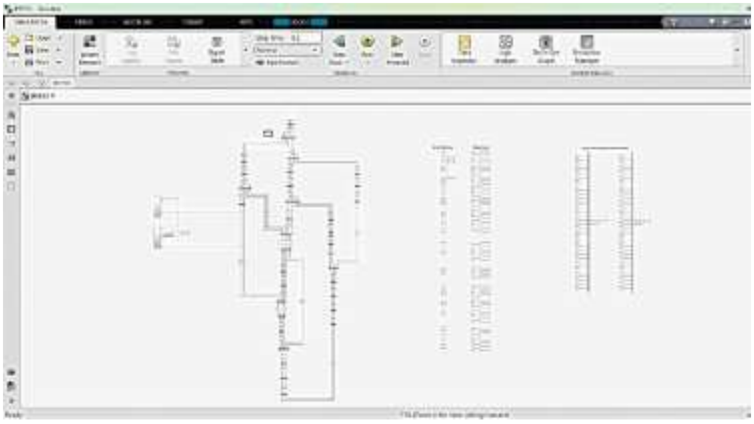

Fig: 5.1 Simulation model of distributed network

Parameter	**With DG**
Power Loss (kW)	3715.1
Voltage Profile (pu)	0.6049

Table:5.2 Simulation result of Distributed network

C) Analysis of Distribution Network With Integrated DG's

The integration of various distributed generation units including wind turbines, photovoltaic (PV) solar, and diesel generators systems was then modeled. Incorporating these DG units at efficiently optimized locations, determined via particle swarm optimization, resulted in notable improvements in the voltage profile across all buses. The presence of DG units helped maintain voltage magnitude, enhancing system reliability and stability. Moreover, overall system power losses were reduced due to local generation supplying loads nearer to consumption points, minimizing feeder current and associated losses. In this system by using PSO algorithm, for efficient optimal placements no. of. iterations have been performed, and at 10th iteration the best fitness has been found as shown in Fig 5.2

This study enhanced the voltage profile as shown in Fig 5.3 which improves the system stability and the total power losses is minimized after integrating DG's as shown in Fig 5.4 and Voltage drop index has been reduced as shown in Fig 5.5 it improves voltage regulation and reduced power losses, and enhanced system efficiency, contributing to better overall reliability and performance of the distribution network.

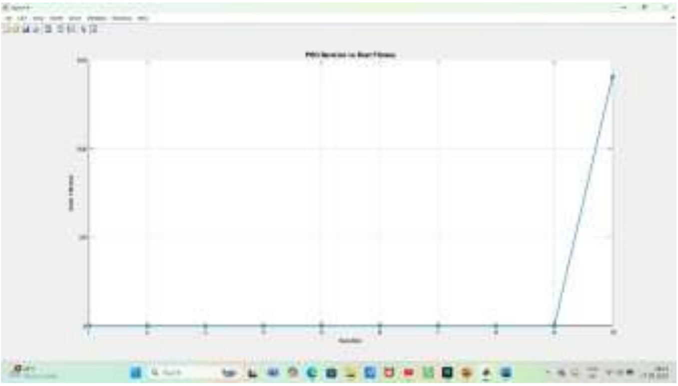

Fig: 5.2 Iteration vs best fitness

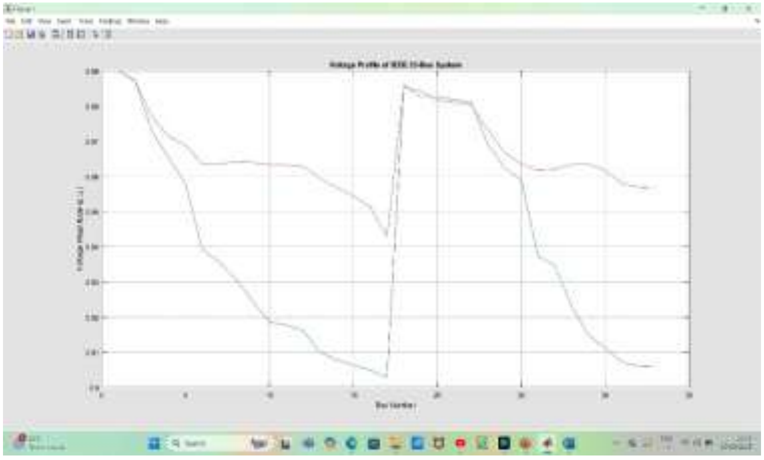

Fig: 5.3Voltage profile of system

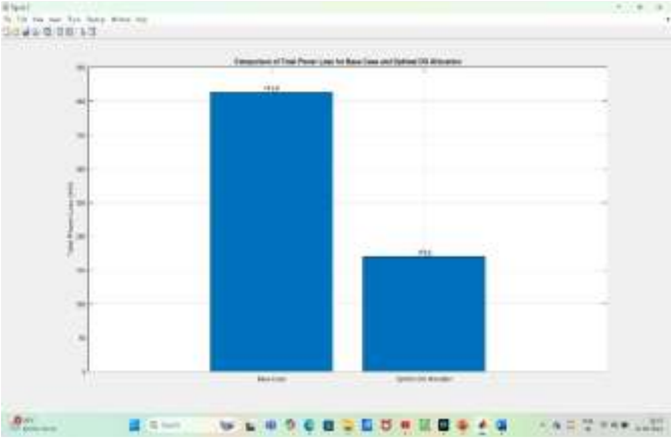

Fig: 5.4 Comparision of power loss

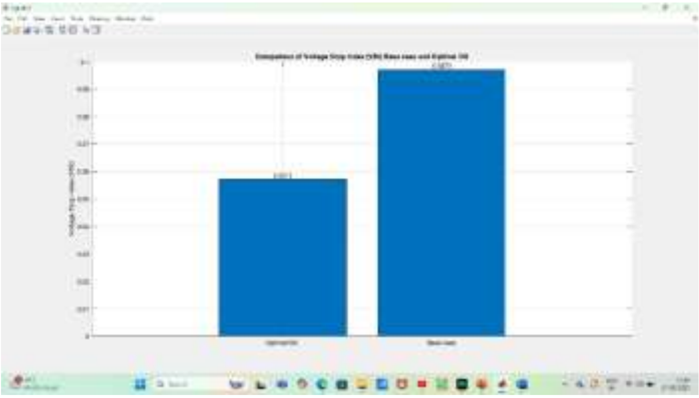

Fig: 5.5 Comparision of Voltage drop index

The Improved voltage profile, reduced power loss and voltage drop index (VDI) is shown in Table 5.3

Parameter	**With DG**
Power Loss (kW)	63.44
Voltage Profile (pu)	0.9529
Voltage Drop Index (VDI)	0.0571

Table: 5.3 Parameters and values after DG

By comparing the table 5.1,table 5.2 and table 5.3, it is clearly shown that the optimal DG placement has significantly improved the voltage profile and minimized the power losses of the system.

CONCLUSION

The integration of distributed generation (DG) technologies such as wind turbines, photovoltaic (PV) and diesel generators systems into the IEEE 33-bus distribution network significantly enhances voltage stability and reduces power losses when appropriately sized and optimally located. In addition improper placement will lead to adverse effects like voltage deviations and increased losses. Strategic planning using advanced load flow and optimization techniques is therefore essential to maximize the benefits of DG integration. This research provides valuable insights for utilities and policymakers aiming to modernize the grid and incorporate renewable resources. Effectively by balancing technical performance with practical constraints, the findings highlight the critical role of optimal DG deployment in achieving a more resilient, efficient, and sustainable power distribution network. This study confirms that proper placement of DG will effectively improve system efficiency and support renewable energy penetration.

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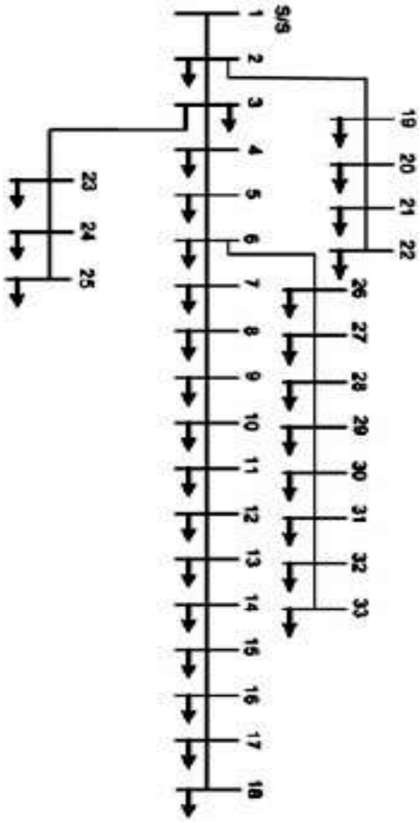
APPENDIX

A) Basic IEEE-33 bus system single line diagram



B) Line Data of Distribution Network Under Study

From Bus	To Bus	Resistance (R) (ohms)	Reactance (X) (ohms)
1	2	0.0922	0.0470
2	3	0.4930	0.2511
3	4	0.3660	0.1864
4	5	0.3811	0.1941
5	6	0.8190	0.7070
6	7	0.1872	0.6188
7	8	1.7114	1.2351
8	9	1.0300	0.7400
9	10	1.0400	0.7400
10	11	0.1966	0.0650
11	12	0.3744	0.1238

12	13	1.4680	1.1550

From Bus	To Bus	Resistance (R) (ohms)	Reactance (X) (ohms)
13	14	0.5416	0.7129
14	15	0.5910	0.5260
15	16	0.7463	0.5450
16	17	1.2890	1.7210
17	18	0.7320	0.5740
2	19	0.1640	0.1565
19	20	1.5042	1.3554
20	21	0.4095	0.4784
21	22	0.7089	0.9373
3	23	0.4512	0.3083
23	24	0.8980	0.7091
24	25	0.8960	0.7011
6	26	0.2030	0.1034
26	27	0.2842	0.1447
27	28	1.0590	0.9337
28	29	0.8042	0.7006
29	30	0.5075	0.2585
30	31	0.9744	0.9620
31	32	0.3105	0.3619
32	33	0.3410	0.5302

Table:

C) Load Data of Distribution Network Under Study

Bus No.	PLoad (kW)	QLoad (kVAR)
1	0	0
2	100	60
3	90	40

4	120	80
5	60	30
6	60	20
7	200	100

Bus No.	PLoad (kW)	QLoad (kVAR)
8	200	100
9	60	20
10	60	20
11	45	30
12	60	35
13	60	35
14	120	80
15	60	10
16	60	20
17	90	40
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	40
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32	90	40
33	90	40