# Voltage Profile and Power Loss Analysis with PSO-Optimized DG Allocation of 220kV/132kV/33kV Substation at Jamshedpur India

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***Abstract:*** *Active and Reactive power optimization is a challenge in which both integer and non-linear programming are involved. Meta heuristics approaches have been shown to be effective in finding the best solutions. The purpose of this study is to examine the use of Particle Swarm Optimization (PSO) inside the MATLAB environment for the purpose of improving reactive power compensation techniques in the ever-changing landscape of the electrical sector, with a specific emphasis on Distributed Energy Resources (DER). This work highlights the inherent significance of reactive power in terms of controlling voltage, enhancing power factor, and reducing system losses. PSO is considered a feasible optimization approach for reactive power dispatch because the study goes into detail on reactive power compensation complexities such as load compensation and voltage support. The research also looks at how distributed generator (DG) allocation affects the performance of the system in general, as well as providing specific details on the necessary hardware and software for efficient substation operation that guarantees both reliability and accuracy. The results reveals that incorporation of DGs into the system along with optimal placement based on the PSO technique has presented viable responses, such as reducing power losses for active and reactive power, respectively, with the addition of three DG units into the network under consideration. This translates into increased energy efficiency and voltage management within the distribution system. Lastly, this paper contributes not only to theoretical advances in power engineering but also has practical implications for sustainable energy systems that are available today. It can also influence the subsequent path of reactive power compensation techniques in the electrical industry.*

**Keywords- Particle swarm optimization (PSO), Distributed generator (DG), Voltage Profile, Real and Reactive power Compensation**

## 1. Introduction

The electrical industry is now experiencing a significant shift because of the emergence of new entities participating in both wholesale and retail markets, such as Distributed Energy Resources (DER) [1]. The level of competition is on the rise in many areas, leading to the

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questioning and disruption of traditional business models [2]. However, there is still a lack of competition in the auxiliary services market, particularly in the reactive power market [3]. One of the auxiliary services that system operators need to acquire is reactive power. This is necessary to keep the voltage of the local electricity network within the acceptable parameters, which is necessary to ensure the efficient operation of electrical power equipment. Reactive power's significance is best grasped by considering its effects on voltage regulation, power factor, and power system losses. These days, ensuring a steady supply of electricity means looking into issues like power quality on the network. One of the methods that can help achieve the goal of a high-quality and reliable electrical power system is the utilization of reactive power compensation [4]. Reactive power compensation is the regulation and management of reactive power in an alternating current (AC) system to optimize system performance. There are two main ways to look at the reactive power compensation problem: load compensation and voltage support. Voltage support aimed to lessen voltage variations at a given terminal of the transmission line [5], while load compensation worked to boost the system's power factor by compensating voltage regulation and removing current harmonic components produced by large and fluctuating nonlinear industrial loads.

There has been a concerted effort made to combat problems that are associated with the optimization of energy in power systems, with a particular emphasis on the optimization of reactive power in the context of smart grids [6]. The emphasis is placed on a wide variety of applications, ranging from the retrieval of harmonic load current to the management of DC-link capacitor voltage and the incorporation of distributed compensators for optimal reactive power flow. In addition, detailed evaluations considering the influence that dynamic loads, induction motors, and solar systems have on power grids. These analyses offer insights into the behavior and performance of the system under a variety of different scenarios. The comparison of different optimization procedures, such as PSO and genetic algorithms, highlights the benefits of specific methodologies in terms of the quality of the solutions they provide and the ease with which they may be computed [7]. Furthermore, real power losses are kept to a minimum, and compliance with voltage stability standards is guaranteed, utilizing data-driven hybrid optimization to meet voltage control issues. The literature as a whole highlights the need for innovative optimization strategies to improve the effectiveness, reliability, and robustness of power systems in the face of changing conditions. In order to do that there need to be development in reactive power compensation techniques such as FACTS technology. Various optimization methods for optimal location and sizing of FACTS devices have been used in this sector. Some of them are Analytical approach, Conventional approach, meta-heuristic approach and hybrid approach. Out of these approaches, meta-heuristic approach and hybrid approach have been proved to be a great optimization technique. Although hybrid approach is better than meta-heuristic approach, but due to its complexity, Particle Swarm Optimization (PSO), a meta-heuristic approach will optimize location and sizing of FACTS devices with an ease [8]

## 2. Application of PSO for Reactive Power Compensation

A power system can benefit from reactive power adjustment by lowering transmission losses and enhancing the voltage profile [9]. Particle swarm optimization (PSO) is a meta heuristic algorithm that can be used to optimize reactive power dispatch. Inspired by the coordinated efforts of animal groups such as flocks of birds or schools of fish, particle swarm optimization is a type of optimization or heuristic search [10]. The birds and fish, henceforth referred to as particles, engage in cooperative communication through a highly complex system. Particles are distinguished not only by their communication capabilities but also by the manner in which they update the most successful performances of the past during the current voyage. Figure 1 depicts how particle swarm optimization works.

The following are some scenarios of how PSO is utilized when applied to the problem of reactive power compensation:

- Optimal placement of capacitors and reactors in a power system and thus regulate the reactive power flow at different places.
- Sizing of Compensation Devices such as capacitors and reactors can be minimised. PSO would look for the optimal mix of device sizes that sustains reactive power at the lowest cost.
- The PSO algorithm can be utilized to optimize the parameters of compensating devices to minimize voltage variations and maintain the voltage within acceptable thresholds, thus ensuring the voltage stability of the power system and voltage profile improvement.
- Reactive power compensation can also be adjusted using PSO to minimize transmission losses.
- PSO can be used to compensate for fluctuations in reactive power in real-time. Thus make instantaneous adjustments to the settings of compensation devices, leading to optimal reactive power supply in a variety of operational contexts.

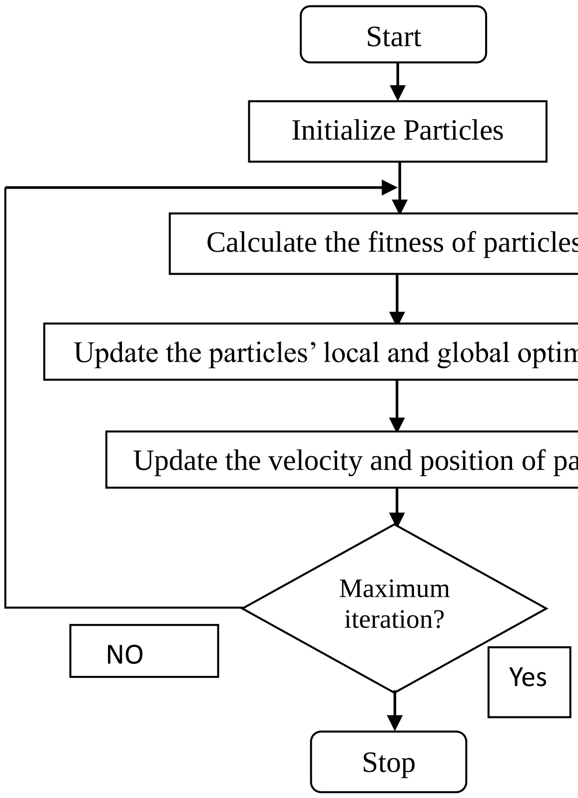


**Figure 1. Particle Swarm Optimization Workflow**

## 3. Research Gap

A 220kV/132kV/33kV substation at Jamshedpur, Jharkhand in India has been facing a lot of problems. The identified problems highlight the need for research to bridge the existing gaps in reactive power compensation. They are

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- Poor Voltage profile due to inefficient reactive power management.
- Impact of low power factor and high system losses.
- Inadequacy of Traditional Approaches: Assessment of the limitations of traditional methods used for reactive power adjustment has to be done. Also the challenges have to be highlighted which the Jamshedpur Substation have been facing.
- Advanced Optimization Techniques need to be adopted to improve reactive power compensation and thus offer a more dynamic response to changing operational conditions and load requirements.
- Introduction of PSO is a potential solution for locating optimal settings for reactive power compensators.

## 4. Methodology

The Jamshedpur substation, an essential part of the power distribution network, is responsible for a significant portion of the effort that goes into converting and delivering electrical power to end users. Steps involved in Optimal voltage profile and power loss optimization by PSO are discussed here.

i. Loading Initial Parameters: Base case parameters from the mat-power case file have been loaded and Power flow has been run, in order to obtain initial power losses and voltage profiles.

ii. Setting up PSO Parameters: The lower and upper bounds for the optimization variables (DG locations and sizes) have been defined. PSO parameters such as the number of particles, lower and upper bounds, and PSO options have been specified.

iii. PSO Optimization: The objective function (objectives) that computes the combined effect of voltage deviations and active power losses for a given set of DG locations and sizes are defined. Using the PSO algorithm (particle swarm), the objective function has been optimized and the optimal DG locations and sizes have been found.

iv. Implementing Results: Integer conditions for DG locations have been applied and the power system have been modified by placing DGs with optimal sizes and locations. Power flow has been run after optimal DG placement.

v. Display and Visualization: The optimal results, including DG locations, sizes, initial and final power losses have been displayed. The initial and final system voltage profiles have been plotted. The total active and reactive power losses before and after DG placement have also been plotted.

vi. Objective Function Calculation: The mean squared error for voltage deviations has been calculated. The ratio of losses with DG to losses without DG (losses index) has also been calculated. The voltage deviation and losses index with specified weights are combined to form the objective function.

## 5. Results, Discussions and Analysis

The result section contains the results of the analysis of the 33-bus distribution system at Jamshedpur substation having 220 kV, 132 kV and 33 kV substations, focusing on two main sections. The first section offers insight into distributed generator (DG) allocation for minimum reactive power generation, optimal active power generation, improved voltage stability, and reduced line losses. Section two examines voltage stability under different loading conditions for four DG count configurations ranging from zero to three. As depicted in the graphs, this DG allocation made the voltage profile better. Moreover, the graphs showed that particle swarm optimization (PSO) reduces the system's active and reactive power loss effectively. Other figures demonstrated how these methods redistribute DGs' power loss across the 33-bus system. This study shows clearly that PSO is highly efficient in optimizing DG placement for low power loses and improved operational efficiency.

### 5.1 Voltage Profile and Power loss Analysis with PS Optimized DG Allocation

The voltage profile shows that after DG allocation, voltage levels are higher in the distribution system because it depicts how distributed generators impact the distribution systems. Figure 2 demonstrates the average voltage contour of a distribution system before and after the allocation of distributed generators (DGs). After DGs have been allocated, it can be seen from the graph that the voltage profile is higher than the initial one.

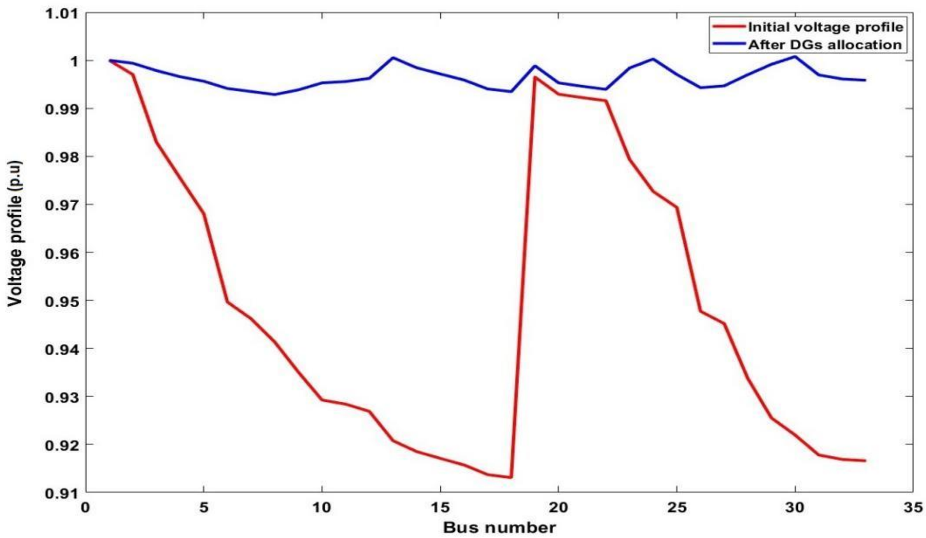


Figure 2. Voltage Profile at Different Points of the Distribution System Before and After DGs allocation

Figure 3 shows the total active power losses and the total reactive power losses for the four scenarios: initial losses(before DG allocation) and after PS Optimized DG allocation DG1, DG2 and DG3. The results provide comparative analysis of two power components in which adding subsequent DGs positively affects the power transmission with minimal losses ranging from 202.677 kW to 12.925 kW in active power loss and 135.1637 kVAR to 11.345 kVAR in reactive power loss.This shows that the overall active power losses are much reduced by using the PS Optimized technique for DG allocation. Similarly it shows that the PSO algorithm has managed to identify the best way of allocating DGs in the distribution system so as to reduce the amount of reactive power lost. Figure 4 shows the results of a conducted study that aimed to establish the efficiency of using distributed generation (DGs) to minimize power losses in the distribution system.

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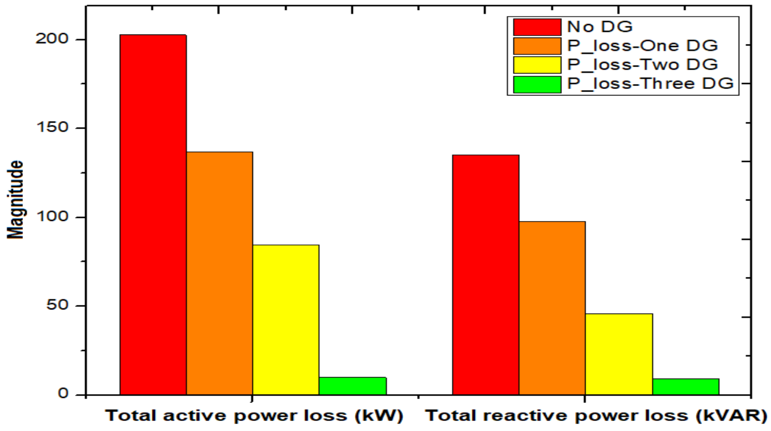


**Figure 3. Active and Reactive Power Losses with Different DGs Configurations**

The blue line on the graph shows the power losses per line before any DGs have been allocated, while the red line indicates what happens to these losses after introducing DGs using the PSO algorithm. It is evident from this plot that there is a significant reduction in power losses when DGs are allocated by means of PSO algorithm. This is because now DGs supply power at optimum located points to the system and hence reduce the amount of power that has to be transmitted through wires or overhead cables.

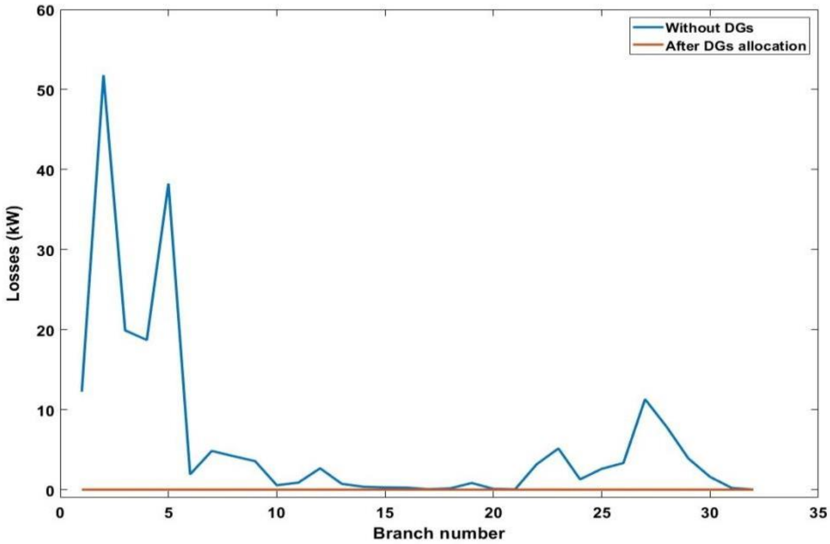


**Figure 4. Power Losses Per Line Before and After DGs Allocation**

Figure 5 shows the plot of a Particle Swarm Optimization (PSO) algorithm which visualizes the objective function values over the course of iterations. The x-axis represents the iteration number, indicating the algorithm's progress in searching for the optimal solution. The y-axis corresponds to the objective function value, signifying the quality of the best solution found so far. Ideally, the plot exhibits a downward trend as the algorithm iterates, signifying its pursuit of better solutions. This trend reflects the decreasing objective function values, indicating improvement. As the plot flattens out, it suggests the algorithm have converged, potentially reaching the optimal solution or a local minimum. The final y-value on the rightmost end represents the best objective function value discovered by PSO.

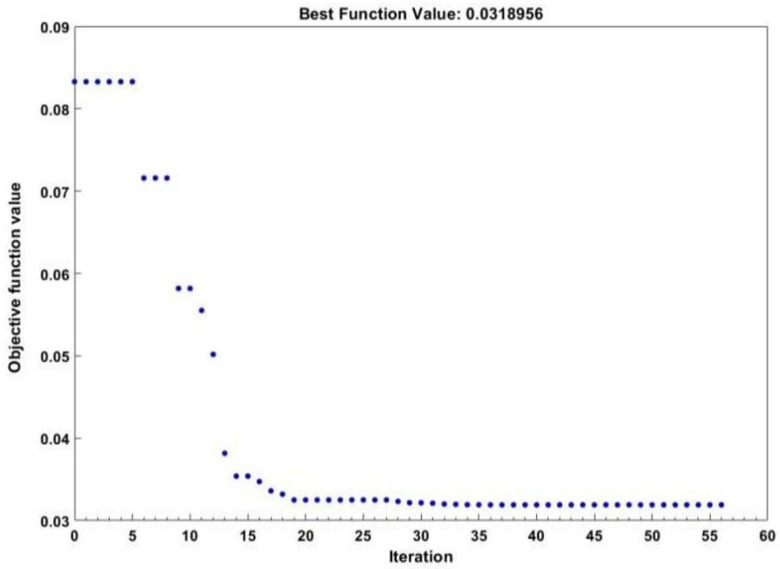


Figure 5. Objective Function Value with Iteration for PSO in DGs Allocation

### 5.2 Optimal Location and Allocation of DGs

Table 1 and Figure 6 demonstrate the significant reduction in power losses achieved by integrating DGs into a 33-bus electrical distribution system. The Table highlights that increasing the number of DGs from zero to three progressively decreases both active and reactive power losses, with optimal reductions respectively, attained with three DGs. The image visually depicts the reconfigured network with these three DGs strategically positioned at buses 1, 23, and 32, aligning with the optimal locations identified in the Table. This combined analysis underscores the effectiveness of DG integration in optimizing power system performance and minimizing energy losses.

Table 1 Impact of Distributed Generation on Power System Losses and Optimal Locations for Active and Reactive Power Loss Reduction

| Parameters | No DG | P_loss-One DG | P_loss-Two DG | P_loss-Three DG |
|---|---|---|---|---|
| **Total System Active Power Loss (kW)** | 202.677 | 136.438 | 86.225 | 12.925 |
| **Active Power Loss Reduction (%)** | - | 32.68% | 57.45% | 93.62% |
| **Total System Reactive Power Loss (kVAR)** | 135.166 | 98.527 | 43.619 | 11.345 |
| **Reactive Power Loss Reduction (%)** | - | 27.11% | 67.73% | 91.61% |
| **Optimal Locations** | - | 1 | 1, 23 | 1, 23, 32 |

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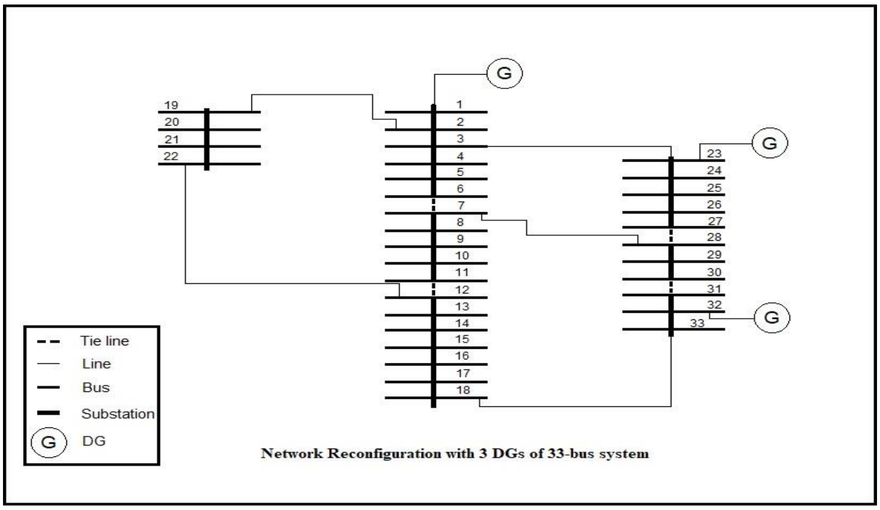


Figure 6. Network Reconfiguration with 3 DGs of 33-bus System

### 5.3 Voltage Stability with Varying Loads in the Network

The analysis of network at different loading condition includes a voltage stability profile of DGs (zero up to three), showing their voltage output at different bus numbers. Furthermore, the active power loss across branches among DGs from 0 – 3 is also examined with an emphasis on reducing active power loss as compared to reactive power loss. PSO is used to illustrate the power loss in the 33-bus distribution system and find out its power loss for every bus. The outcomes underscore the effectiveness of strategic placement of DGs and minimizing distribution losses using PSO in reducing power losses in a distribution system. The maximum bus voltage stability value can be observed at Bus 1 with a value of 0.980349, while the minimum bus voltage stability is found at Bus 33 with a value of 0.870324. Figure 7 shows the voltage stability profile of four DGs: DG-0(blue), DG-1(green), DG-2(red) and DG-3(pink). This displays the voltage output of each DG at various bus numbers.

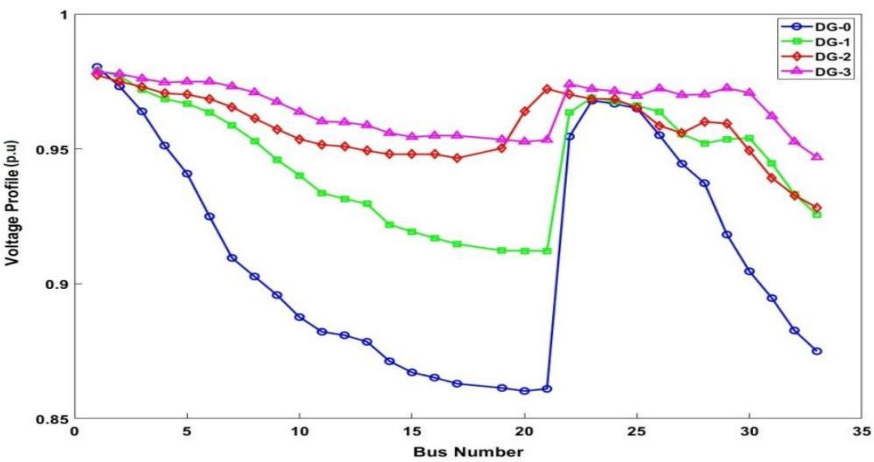


Figure 7. Voltage Profile at Different Points of the Distribution System with Different DG Configuration and Load Variation

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Active power loss is one major consideration that needs to be considered in the design of distribution systems involving DGs. The deliberate arrangement of DGs coupled with branch length and resistance can reduce power dissipation and increase system efficiency. Figure 8 shows active power loss along the branches for 4 different DG configurations. The minimum active power loss on any branch is 0.1192 kW, and the maximum active power loss is 31.7984 kW.

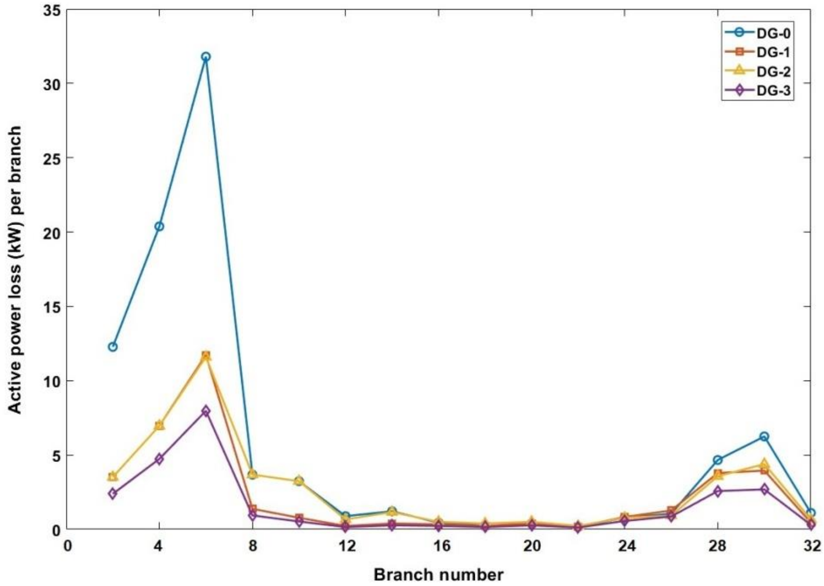


**Figure 8. Active Power Losses with Branch Number in Distribution System with Varying Load.**

Different distributed generators have different reactive power losses (Q_loss) per branch. DG-0 has the maximum reactive power loss per branch, and it ranges between about 0.65 kVAR and 46.90 kVAR. The lowest values are found in DG-3, where they range from approximately 0.15 kVAR to 14.72 kVAR. Figure 9 shows Q_loss for four different DG configurations i.e. DG-0, DG-1, DG-2 and DG-3.

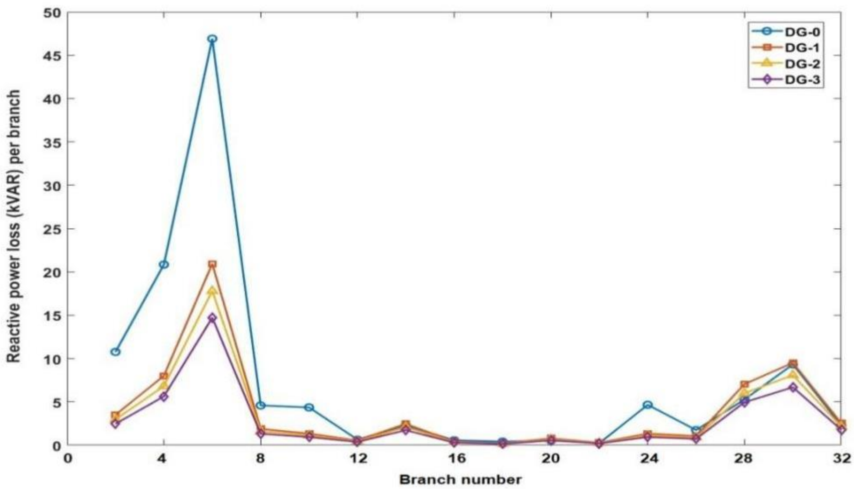


**Figure 9. Reactive Power Losses with Branch Number in Distribution System with Varying Load.**

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The bar graphs in Figure 10 show the comparative analysis between the total reactive and active power loss with each DG sets. In all four DG sets configuration, the active power loss is higher than the reactive one initially which keeps decreasing with each added DGs in the subsystem. It ranges from 111.71 kW to 82.58 kW showing control over load variation and robustness in the system performance. The reactive power loss is about 65% lower than the active one initially which keeps decreasing with each added DGs in the subsystem. It ranges from 72.916 kVAR to 51.43 kVAR showing optimal control over load variation and robustness in the system performance.

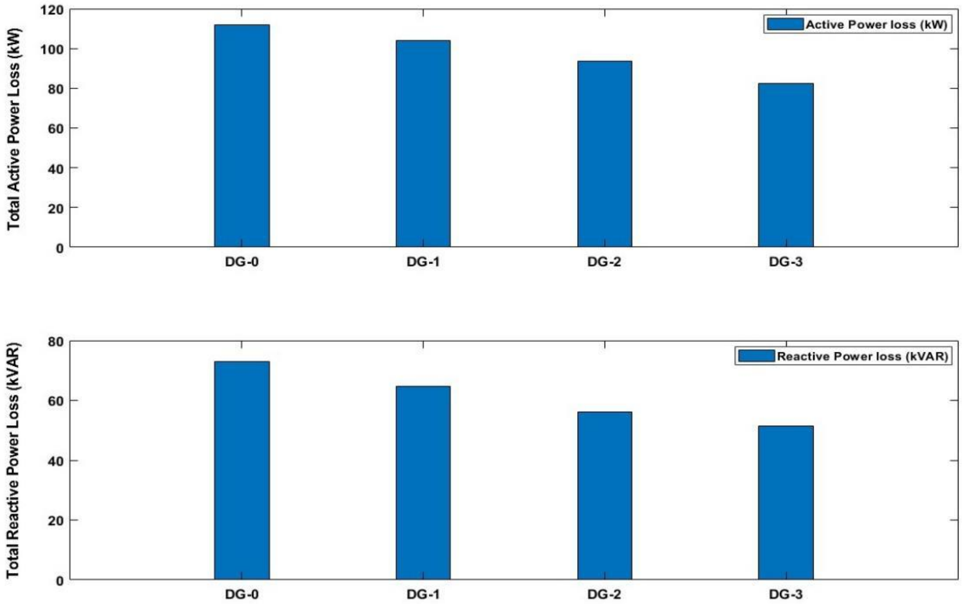


**Figure 10. Total Active and Reactive Power Losses in Distribution System with Varying Loads.**

Figure 11 shows the plot of a Particle Swarm Optimization (PSO) algorithm convergence curve of objective function value for each iteration with varying load. The final y-value on the rightmost end represents the best objective function value discovered by PSO i.e. 2.563. It shows the solution obtained from simulation confirms with the output.

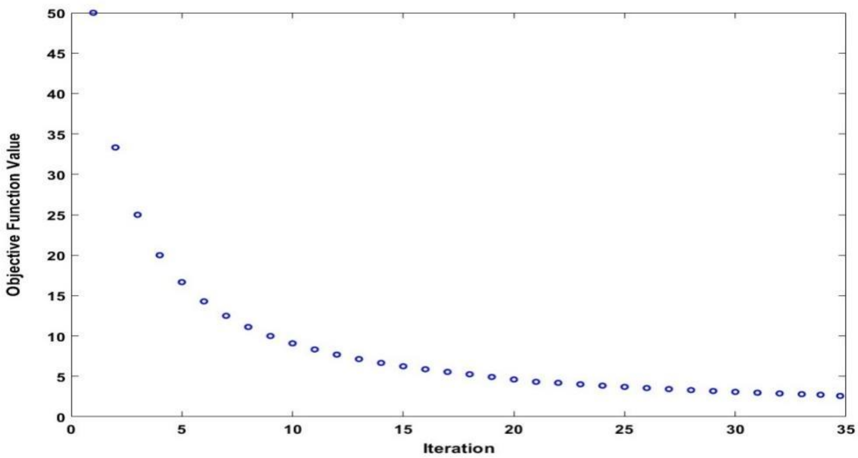


**Figure 11. Objective Function Value with Iteration for PSO in DG Load Variation**

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The 33-bus distribution system's power loss is described in the bar graph. It draws attention to the buses that lose more or less electricity. Particle swarm optimization (PSO) convergence plot was used to determine the power loss profile for each bus in a 33-bus distribution system, as shown in Figure 12. As the number of PSO iterations rises, the power loss converges initially but rises in between at bus number 20 for which DG control or subsidiary line connection to the main line is required to control the power loss and a DG source is added to Bus 23 close to the middle. Finally, the solution converges back towards the end of SLD, as seen in the PSO convergence curve. It is clearly visible from the PSO convergence plot in each case that allocating more and more DGs provides better response to the power loss control strategy in the substation then load flow control approach.

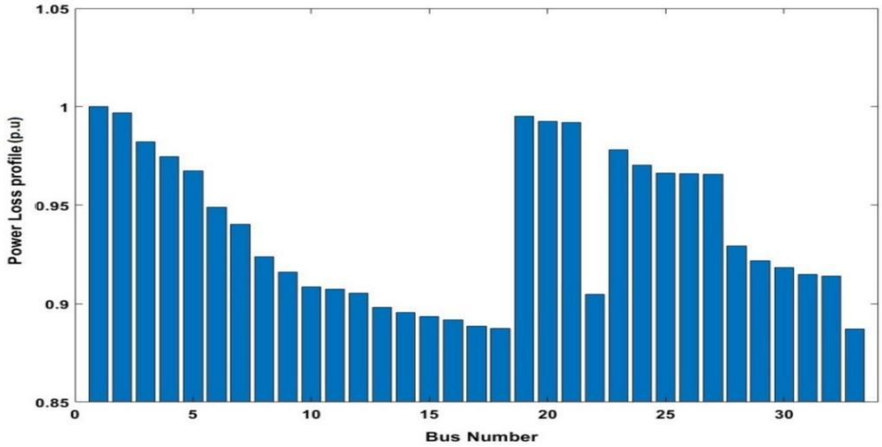


**Figure 12. PSO Convergence Plot for Power Loss Profile in a Single Line 33 Bus Distribution System along the Network with Varying Loads at Different Locations.**

Different sets of distributed generators (DGs) at different buses result in a comparison between active and reactive power losses, as shown in Table 2. These are total system active power loss, active power loss reduction percentage, total system reactive power loss, reactive power loss reduction percentage, optimal locations for DG placement and the corresponding DG sizes. In each column, the values represent results for different numbers of DGs (none to three) at different buses. Table 2 shows DG load variation affects in both active and reactive power loss in the 33-Bus system.

**Table 2. Active and Reactive Power Loss in the System with Varying Loads.**

| Parameters | No DG | P_loss-One DG | P_loss-Two DG | P_loss-Three DG |
|---|---|---|---|---|
| **Total System Active Power Loss (kW)** | 111.71 | 103.98 | 93.47 | 82.58 |
| **Active Power Loss Reduction (%)** | - | 6.92% | 16.32% | 26.07% |
| **Total System Reactive Power Loss (kVAR)** | 72.48 | 64.79 | 56.22 | 51.43 |
| **Reactive Power Loss Reduction (%)** | - | 10.61% | 22.43% | 29.04% |
| **Optimal Locations** | - | 1 | 1, 23 | 1, 23, 32 |

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## 6. Conclusion and Future Scope

Distributed generator (DG) allocation and its impact on system performance in a 33-bus distribution system at the Jamshedpur substation that integrates power from 220kV, 132kV and 33kV substations were valuable insights obtained from the comprehensive study. The study discussed the benefits of DG placement regarding minimum reactive power generation, optimal active power generation, better voltage stability and reduced line losses. The results showed great improvement in voltage profiles but also significant reductions in active and reactive power losses when applying PSO for DG placement. The voltage stability profile for DGs presented improved voltage output at some bus numbers, stressing on beneficial effects for strategic DG positions.

Several possibilities for improving power system optimization could come through future research potential. Be more attentive to the compensatory strategy based on Particle Swarm Optimization (PSO) and find out how this research could determine its improvement. The exploration of feasible techniques to optimize algorithm parameters, enhance convergence rate, and study adaptive schemes within PSO is of great interest. With these improvements, it would be possible to apply the approach in different power systems enhancing efficiency as well as making it more reliable. It can be achieved by integrating adaptive learning algorithms with intelligent decision-making systems in a PSO-based technique to improve its capability of adapting and reacting in real-time. The ultimate future potential is to develop the PSO algorithm through advanced technology alongside scaling it through extensive evaluations. These enhancements would hence enhance various methods for handling reactive power, making them adaptable to different operating situations of power systems and supporting their integration into sustainable energy systems.

## 7. References

[1]. Anaya, Karim L., and Michael G. Pollitt. "Reactive power procurement: A review of current trends." Applied Energy, vol. 270, issue C, no S0306261920304517, (**2020**).

[2]. Esobinenwu, Chizindu Stanley and E. T. Oniyeburutan, "Reactive power (VAR) compensation techniques in high voltage transmission lines," Global Journal of Engineering and Technology Advances, vol. 16, no. 01, **(2023**), pp. 024-029.

[3]. Tabatabaei, N. M., A. Jafari and N. S. Boushehri, "A survey on reactive power optimization and voltage stability in power systems," International Journal on Technical and Physical Problems of Engineering (IJTPE), vol. 6, no. 18, (**2014**), pp. 220-233.

[4]. Ayalew, Frie, Seada Hussen and Gopi Krishna Pasam. "Reactive Power Compensation: A Review," International Journal of Engineering Applied Sciences and Technology, vol. 3, no. 1, (**2019**), pp. 1-7.

[5]. Ibekwe, B. E., C. A. Mgbachi and N. H. Nwobodo, "Reactive power compensation using 500kV, 180km line to maintain substantially flat voltage profile at all levels of AC transmission system," International Journal of Advanced Research in IT and Engineering, vol. 6, no. 9, (**2017**), pp. 1-12.

[6]. Zaidan, Majeed Rashid, and Saber Izadpanah Toos, "Optimal location of static var compensator to regulate voltage in power system," IETE Journal of Research, vol. 69, no. 4, (**2023**), pp. 2177-2185.

[7]. Bidyanath, Khaidem, Sanasam Dhanabanta Singh and Shuma Adhikari. "Implementation of genetic and particle swarm optimization algorithm for voltage profile improvement and loss reduction using capacitors in 132 kV Manipur transmission system." Energy Reports, vol. 9, (**2023**), pp. 738-746.

[8]. Bazilah Ismail, Noor Izzri Abdul Wahab, Mohammad Lutfi Othman, Mohd Amran Mohd Radzi, Kanendra Naidu Vijyakumar and Muhammad Najwan Mat Naai, "A Comprehensive Review on Optimal Location and Sizing of Reactive Power Compensation Using Hybrid-Based Approaches for Power Loss Reduction, Voltage Stability Improvement, Voltage Profile Enhancement and Loadability Enhancement", IEEE Access Multidisciplinary Journal, (**2020**) vol 8, pp. 2169-3536 .

[9]. Suliman, Mohammed Y, "Voltage profile Improvement using Static Synchronous Compensator STATCOM," Journal of Information, Communication and Intelligence Systems, vol.1, no. 2, (**2023**), pp. 36-42.

[10]. Aljendy, Raseel I., Rinat R. Nasyrov, Hamdy M. Sultan and Ahmad A. Zaki Diab. "Bio-inspired Optimization Techniques for Compensation Reactive Power and Voltage Profile Improvement in the Syrian Electrical Distribution Systems." Proceedings of the IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), pp. 928-933. IEEE, **2019**https://doi.org/10.1109/EIConRus.2019.8656900 28-31 January 2019 IEEE Conference (**2019**) Conference Location**:** Saint Petersburg and Moscow, Russia.

[11]. Amos Gilat(Department of Mechanical Engg. The Ohio State University), “MATLAB-An Introduction with Applications”, Wiley Publication, Reprint in 2009 ISBN :978-81-265-1394-9.

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