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# Voltage Profile Improvement in Distribution System Using War Strategy Algorithm

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**A B S T R A C T :**

This study proposes an innovative optimization framework for capacitor placement in distribution networks under varying load conditions—light (80%), nominal (100%), and heavy (120%) loading scenarios. The War Strategy Optimization (WSO) algorithm, inspired by tactical principles of military operations, is employed to effectively balance exploration and exploitation in the search process. The central aim is to reduce real power losses and improve system performance through optimal placement of one, two, and three capacitors within the network. The IEEE 33-bus distribution system is adopted as the test environment due to its relevance and frequent use in evaluating distribution optimization techniques. Simulation results indicate that the WSO algorithm delivers consistent improvements in power loss reduction across all load levels and capacitor combinations, surpassing the performance of conventional optimization methods. Noteworthy features of the WSO include rapid convergence, strong resistance to entrapment in local optima, and the ability to adapt parameters in response to system dynamics. This work demonstrates the WSO algorithm's effectiveness and adaptability, positioning it as a promising solution for enhancing the operational efficiency of modern distribution systems.

**Keywords**: Capacitor Placement, Distribution System, Power loss minimization, Voltage profile improvement, War Strategy Optimization.

## 1. Introduction

Electric power systems are critical to modern life, ensuring the delivery of energy from generating stations to end-users. Among the various segments of the power system, the distribution network plays a pivotal role, bridging the gap between substations and consumers. Despite its importance, distribution systems are the most vulnerable part of the power network, characterized by significant energy losses and operational inefficiencies. These challenges necessitate constant innovation and optimization to ensure reliable and efficient power delivery. The distribution system primarily operates at low to medium voltages, facilitating the supply of power to residential, commercial, and industrial consumers. Due to its proximity to diverse load demands and network complexities, the distribution system often experiences voltage drops, power losses, and reduced reliability. Addressing these issues is essential for enhancing the overall efficiency and performance of the electrical grid. Several strategies have been proposed to reduce power losses and improve voltage profiles in distribution systems, including: 1. Network Reconfiguration, 2. Use of Distributed Generation (DG), 3. Implementation of Voltage Regulators, 4. Reactive Power Compensation. Among these, reactive power compensation through optimal capacitor placement has emerged as one of the most effective and economical solutions.

Efficiency and cost-effectiveness in power distribution systems hinge significantly on the strategic deployment of capacitors [1] - [3]. The continuous quest to minimize power losses and elevate system performance necessitates innovative methodologies adept at navigating the complexities inherent in optimization landscapes [4] – [6]. This study embarks on an innovative approach, harnessing the War Strategy Optimization (WSO) algorithm to address the intricate challenge of optimal capacitor placement within distribution networks. The pursuit of reducing power losses and augmenting energy efficiency in distribution systems has spurred the exploration for optimization techniques capable of balancing exploration and exploitation. Conventional methodologies often encounter hurdles related to local optima convergence, adaptability to varying landscapes, and computational efficiency, highlighting the exigency for a more adaptive and robust optimization approach. Inspired by military strategies, the War Strategy Optimization (WSO) algorithm presents a promising paradigm for surmounting these optimization challenges [7] - [9]. Analogous to the coordinated manoeuvres of soldiers, squads, and battalions in a wartime scenario, the WSO algorithm orchestrates a collaborative search and adaptation mechanism within the solution space. This intricate framework adeptly balances exploration and exploitation, enabling efficient navigation across the optimization landscape. This research underscores the application of the WSO algorithm specifically for the critical problem of optimal capacitor placement in power distribution systems. By capitalizing on the algorithm's dynamic adaptation, resilience against local optima, and efficient convergence attributes, the primary objective is to markedly mitigate power losses within the distribution network. The efficacy of the proposed WSO-based approach undergoes rigorous evaluation through extensive simulations conducted on the widely-recognized IEEE 33-bus test system, showcasing its potential in comparison to conventional techniques.

## 2. Illustrations

Comprehensive analysis of the WSO algorithm's performance, juxtaposing it against other cutting-edge optimization methods. The scrutiny encompasses various dimensions including solution quality, convergence speed, adaptability, and the efficacy of WSO's adaptive parameter tuning mechanism. Additionally, it explores the algorithm's scalability to larger networks and contemplates the integration of diverse objective functions, such as voltage stability and reactive power compensation. The outcomes presented herein signify substantial progress in leveraging the WSO algorithm as a potent tool for optimal capacitor placement in distribution systems. Such advancements hold the promise of not only bolstering energy efficiency but also curtailing operational costs, addressing critical concerns within the power distribution domain Subsequent sections elaborate on the intricacies of the WSO algorithm, the methodology devised for optimal capacitor placement, the experimental setup, detailed results, and an extensive discussion of implications and potential future directions in this domain. To evaluate the robustness and accuracy of the proposed algorithm, employ the IEEE 33 bus radial distribution system as a standard test bed as shown in fig.1. It's a globally recognized standard for testing power system algorithms, facilitating comparison with other research findings. Its structure and parameters mirror those commonly found in practical distribution networks. forward-backward sweep technique for loss calculation in the IEEE 33 bus system as part of your proposed algorithm evaluation. This is a common and accurate method for calculating power losses in radial distribution systems like the IEEE 33 bus system [10] – [12].

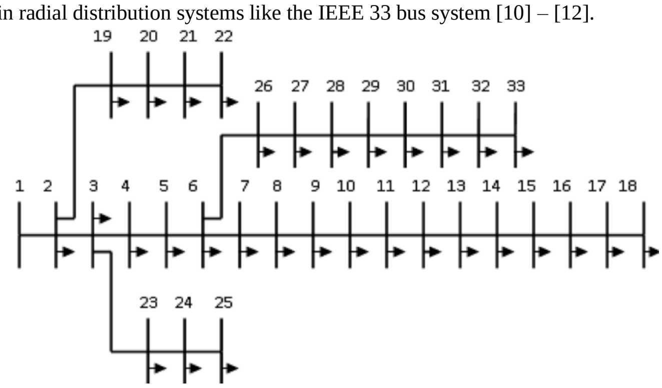


**Fig. 1 – IEEE 33 bus test system.**

## 3. Proposed Methodology

***WSO Algorithm***

1. Initialization: Create battalions of soldiers (particles) with random positions. Squad Skirmishes: Soldiers within each squad share information and adjust their positions based on their own best findings and the best findings of their squad mates (exploration).
   Soldier Position Update:
   $$X_i(t+1) = X_i(t) + 2 * \rho * (C - K) + rand * \left(W_i * K - X_i(t)\right) \quad (1)$$

- $X_i(t+1)$: Updated position of soldier i at iteration t + 1.
- $X_i(t)$: Current position of soldier i at iteration t
- ρ: Random number between 0 and 1
- C: Position of the commander
  (local best solution within the squad)
- K: Position of the king
  (global best solution across all soldiers)
- $W_i$: Weight factor representing morale
  (dynamically adjusted)
- rand: Random number between 0 and 1
  (introduces randomness for exploration)

2. Battalion Recon: Battalion commanders (elite solutions) exchange information and update their strategies based on the best solutions across all squads (exploitation).
   Morale (Wi) Update:
   $$W_i = W_i^0 * e^{(-\alpha * t/T)} \quad (2)$$

- $W_i^0$: Initial morale value
- α: Morale decay rate
- t: Current iteration
- T: Maximum number of iterations

3. Squad and Battalion Formation: Soldiers are divided into squads and battalions based on problem size and desired diversity. Squads and battalions have their own commanders (local and global best solutions). Battlefield Advance: Soldiers move towards promising areas guided by their updated squad and battalion strategies, avoiding captured enemy positions. Repeat & Refine: Repeat steps 2-4 until the desired convergence criteria are met.

Benefits of WSO:

- Efficient exploration and exploitation: Balancing both leads to potentially faster convergence and better solutions.

- Diversity and collaboration: Multiple strategies within battalions enhance global search and prevent premature convergence.
- Dynamic behavior: Adapts to the problem landscape and avoids getting stuck in local optima.

Limitations of WSO:

- Parameter tuning: Choosing appropriate values for morale and other parameters can be challenging.
- Computational cost: Large populations and frequent information exchange can increase computational demands.

**Table I: Key Algorithm Parameters for WSO**

| S. No. | Parameters | Values |
|---|---|---|
| 1 | Population | 50 |
| 2 | Max. Iterations | 200 |
| 3 | Adaption Rate | 0.1 |
| 4 | Max. no. of capacitors | 3 |
| 5 | Adaptive C1 | C1*w |
| 6 | Adaptive C2 | C2*w |
| 7 | Enemy influence in WSO C3 | 1 |
| 8 | Inertia weight wmin | 0.4 |
| 9 | Inertia weight wmax | 0.9 |
| 10 | Range of random numbers for velocity initialization R | 10 |

The placement of a capacitor in a distribution system can help to reduce active power losses and improve voltage regulation. The size and location of the capacitor are important factors in determining its effectiveness and WSO parameters are discussed in Table I.

**Scenario 1: Single capacitor placement**

In this scenario three cases are considered case1, case 2, case 3, represents 80%, 100%, 120% loading of the distribution system its capacity.

***Case 1: 80% of Distribution System Capacity***

The fig. 2, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 30 bus in distribution system. The size of the capacitor is 1200 kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 125.7939kW to 89.9682kW.

Here, “IEEE 33” bus system is considered to examine the proposed algorithm and three scenarios are considered to test the algorithm’s reliability and accuracy under dynamic conditions.

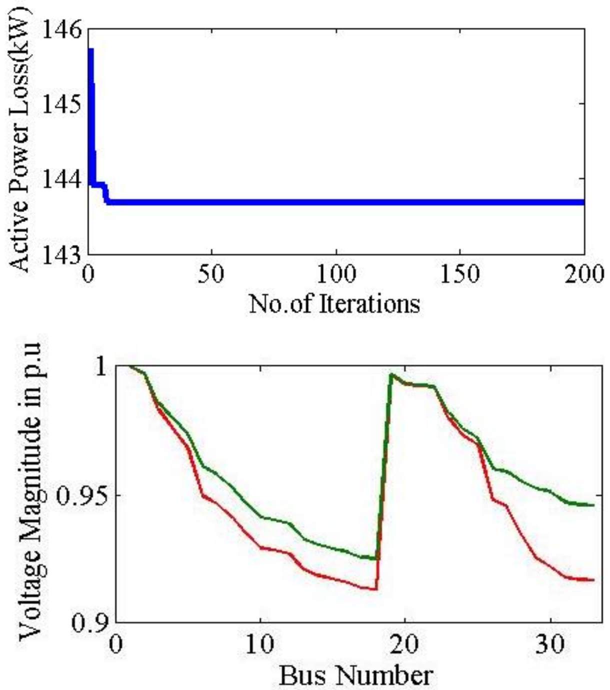


**Fig. 2: Voltage profile and active power losses of 80% distribution system loading.**

***Case 2: 100% of Distribution System Capacity***

The fig. 3, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement & power losses. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 30 bus in distribution system. The size of the capacitor is 1200 kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 202.6617 kW to 143.6850 kW.

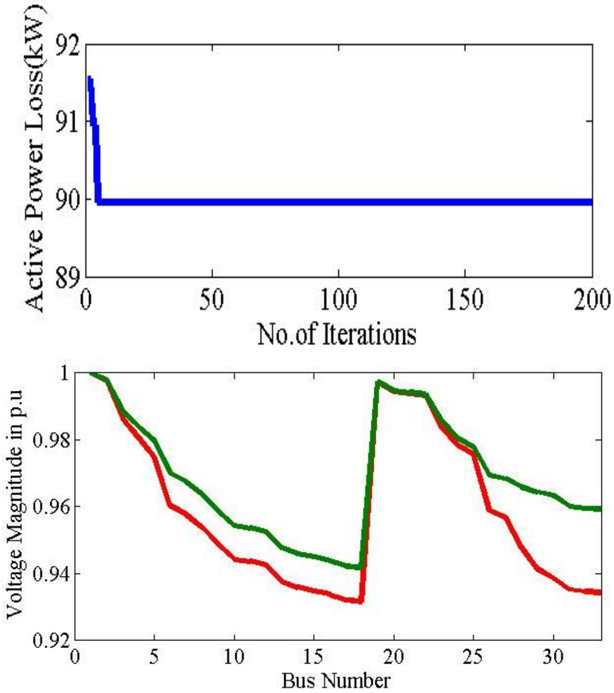


**Fig. 3: power losses in distribution system experiences 100% loading.**

***Case 3: 120% of Distribution System Capacity***

The fig. 4, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement & power losses. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 30 bus in distribution system. The size of the capacitor is 1050 Kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 301.4302 kW to 211.6204 kW.

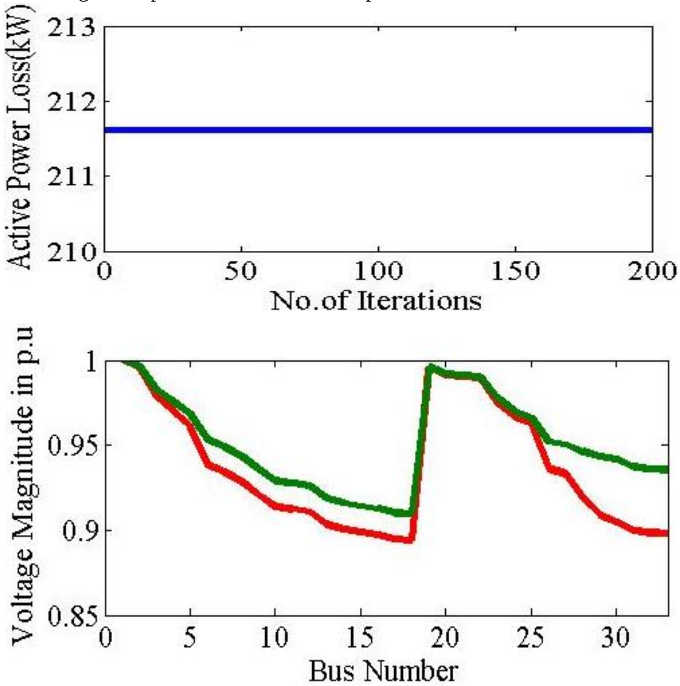


**Fig. 4: Voltage profile and active power losses of 120% distribution system loading.**

***Scenario 2: Two capacitors placement***

In this scenario three cases are considered case1, case 2, case 3, represents 80%, 100%, 120% loading of the distribution system its capacity.

***Case 1: 80% of Distribution System Capacity***

The fig. 5, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 30, 23 buses in distribution system. The size of the capacitors are1050, 1050 kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 125.7939 kW to 88.9520 kW.

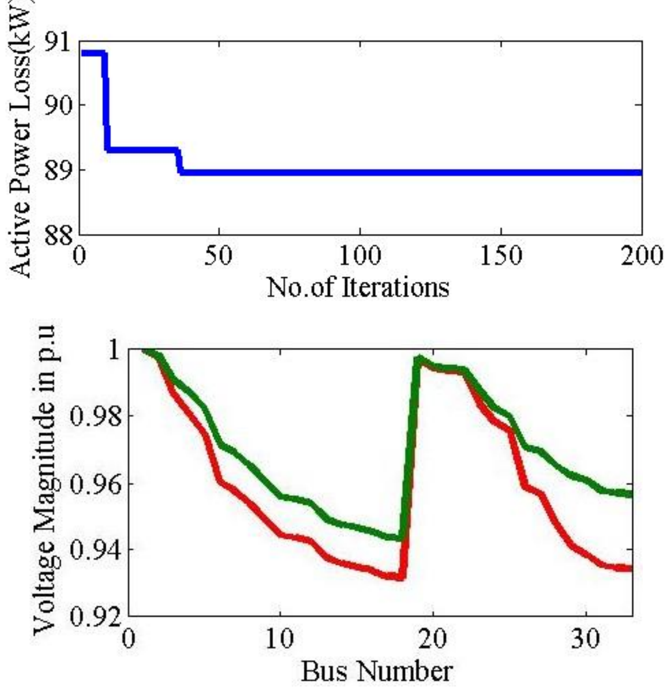


**Fig. 5: Voltage profile and active power losses of 80% distribution system loading.**

***Case 2: 100% of Distribution System Capacity***

The fig. 6, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 30, 23 buses in distribution system. The size of the capacitors are1050, 1050 kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 202.6617 kW to 140.0254 kW.

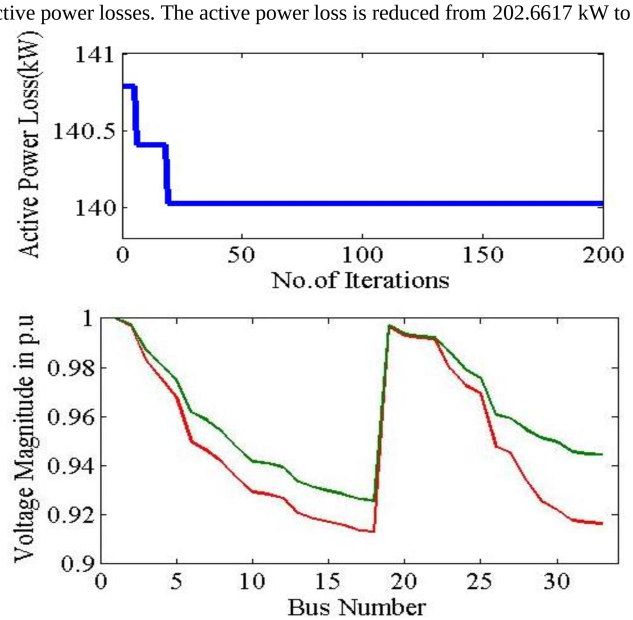


**Fig. 6: Voltage profile and active power losses of 100% distribution system loading.**

***Case 3: 120% of Distribution System Capacity***

The fig. 7, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement & power losses. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 8 & 30th buses in distribution system. The size of the capacitors is 900, 1200 Kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 301.4302 kW to 200.4146 kW.

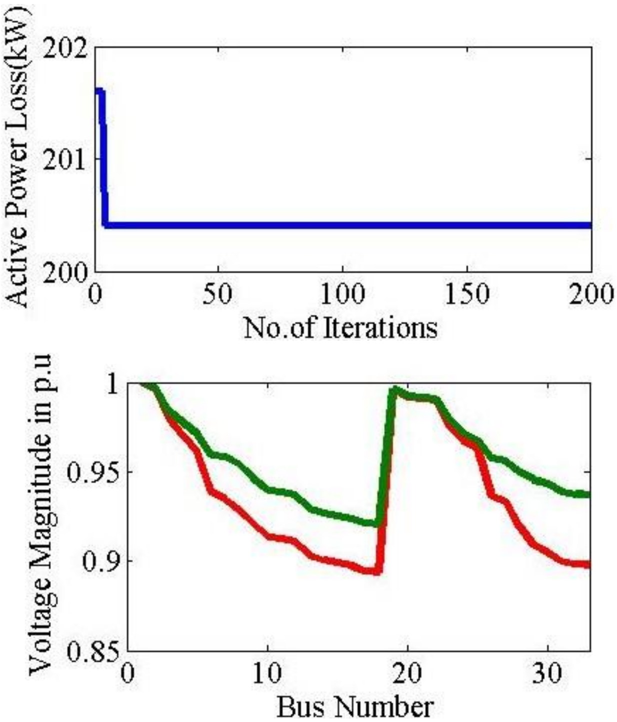


**Fig. 7: Voltage profile and active power losses of 120% distribution system loading.**

***Scenario 3: Three capacitors placement***

In this scenario three cases are considered case1, case 2, case 3, represents 80%, 100%, 120% loading of the distribution system its capacity.

***Case 1: 80% of Distribution System Capacity***

The fig. 8, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement.

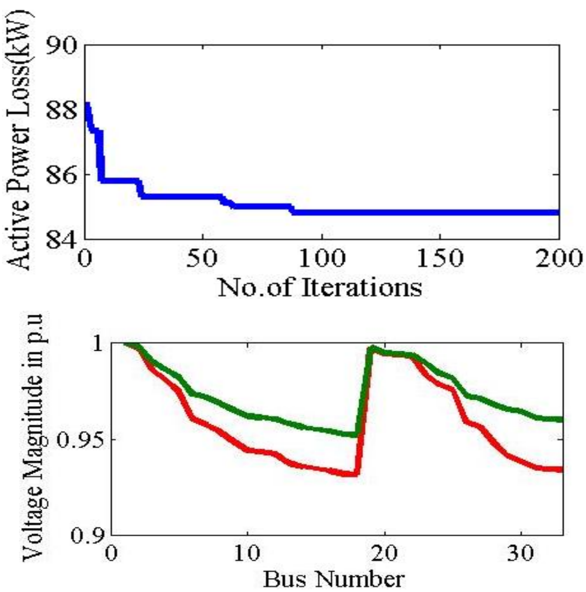


**Fig. 8: Voltage profile and active power losses of 80% distribution system loading.**

The capacitor is also effective in improving voltage regulation by the capacitor is placed at 23, 30, 13 buses in distribution system. The size of the capacitors is 900, 900, 300 kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 125.7939 kW to 84.8179 kW.

***Case 2: 100% of Distribution System Capacity***

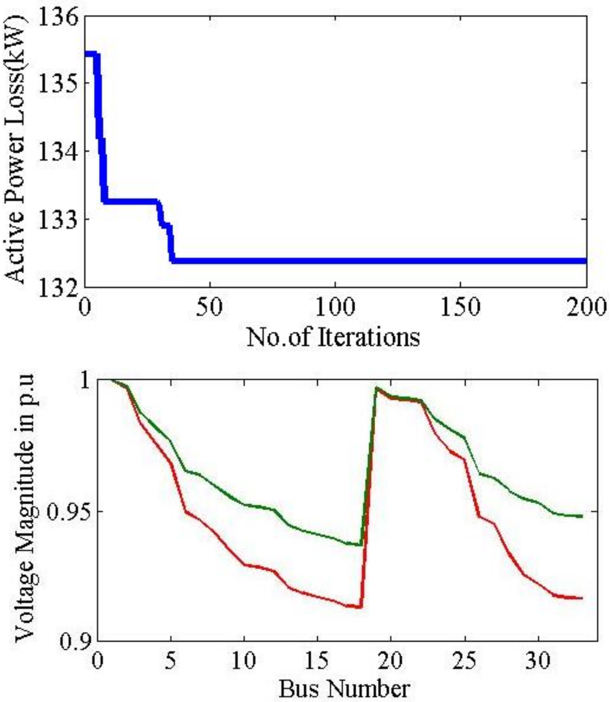


**Fig. 9: Voltage profile and active power losses of 100% distribution system loading.**

The fig. 9, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 24,12, and 30th buses in distribution system. The size of the capacitors is 600, 450, and1050 Kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 202.6617 kW to 132.3797 kW.

***Case 3: 120% of Distribution System Capacity***

The fig. 10, shows the voltage magnitude of the IEEE 33 bus system with and without capacitor placement & power losses. The capacitor is also effective in improving voltage regulation by the capacitor is placed at 8 & 30th buses in distribution system. The size of the capacitors is 900, 1200 Kvar. The results show that the capacitor is effective in reducing active power losses. The active power loss is reduced from 301.4302 kW to 200.4146 kW.

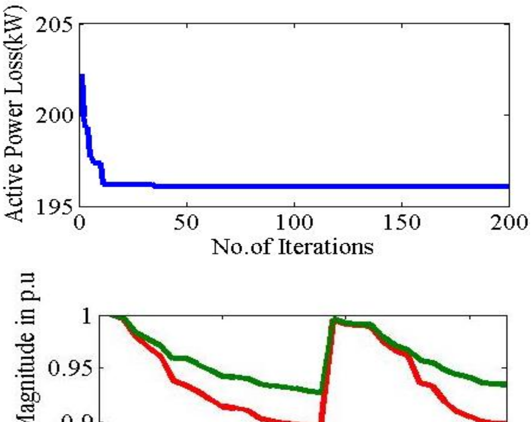


**Fig. 10: Voltage profile and active power losses of 100% distribution system loading.**

The optimal capacitor size varies depending on the number of capacitors used and the system loading. Single capacitor setups require larger sizes (1200-1050 kvar) compared to double and triple placements (combination of 750-1350 kvar and 600-1050 kvar, respectively). This suggests that distributing the reactive power across multiple smaller capacitors can achieve similar or even better results with more flexibility. Proposed WSO algorithm outperforms other algorithms in terms of power loss reduction as shown in table 5, achieving a 29.8% reduction compared to 25.61% for GA [13], 27.56% for BAT [14], and 23.62% for PSO [15]. WSO also achieves the highest minimum voltage (Vmin) of 0.924847 PU, indicating better voltage regulation compared to other algorithms. The maximum voltage (Vmax) values are relatively similar across all algorithms, with WSO achieving 0.997429 PU.

## 4. Conclusion

This paper introduced an effective optimization strategy for capacitor placement in distribution systems using the War Strategy Optimization (WSO) algorithm. The proposed method successfully minimizes power losses under varying load conditions—light, nominal, and heavy—by dynamically adjusting its search behavior. Key outcomes of this study include:

Effective Power Loss Minimization: The WSO algorithm consistently delivers lower power losses across single, double, and triple capacitor installations, outperforming conventional optimization techniques.

Robustness and Adaptability: The algorithm demonstrates strong resilience to local optima and maintains stable performance across diverse scenarios, thanks to its dynamic adjustment capabilities and efficient convergence behavior.

Validation Through Benchmark Testing: Performance assessments conducted on the IEEE 33-bus distribution system confirm the algorithm's reliability and practical applicability under a range of loading conditions.

Superior Optimization Performance: Compared to other approaches, WSO offers improved solution quality, quicker convergence, and greater adaptability across different system configurations.

Adaptive Parameter Control: The built-in mechanism for parameter tuning within WSO further enhances its optimization effectiveness, ensuring consistent results across multiple operating scenarios.

Overall, the results affirm WSO's potential as a reliable and adaptive optimization technique for power loss reduction in modern distribution networks.

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