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Block-chain Enabled Strategies for Efficient Power Loss Management in Distribution Networks

Dr. M. Rama Prasad Reddy[1], P Sailesh Babu[2], K Giridhar[3], Rudresha S J[4], *Chodagam Srinivas[5], and Siva Ramaiah Yenugu[6]

[1]*Department of EEE, G.Pullaiah College of Engineering and Technology, Kurnool, Andhra Pradesh, India*
2Department of EEE, SRKR Engineering College, Bhimavaram, Andhra Pradesh, India
[3]*Department of CST, Madanapalle Institute of Technology & Science; Madanapalle, Andhra Pradesh, India*
[4]*Department of EEE, PESITM, Shimoga, India*
[5]*Department of EEE, Madanapalle Institute of Technology & Science, Madanapalle, Andhra Pradesh*
[6]*Department of CSE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Vadeswaram, Andhra Pradesh*

***Correspondence:** Chodagam Srinivas; *srinivas.chodagam@gmail.com*

ABSTRACT- This study proposes a novel methodology for optimizing capacitor placement in distribution networks, employing the War Strategy Optimization (WSO) algorithm integrated with adaptive parameter tuning and block-chain technology. The WSO algorithm, inspired by military strategies, strategically positions fixed kVAR capacitors at variable locations to minimize power losses and enhance voltage profiles. The adaptive parameter tuning dynamically adjusts algorithm parameters to improve optimization efficiency, while the incorporation of block-chain ensures secure and verifiable optimization results. The methodology is tested on the IEEE 33-bus test system under different loading conditions (80%, 100%, and 120%), representing light, normal, and heavy load scenarios. Simulation results demonstrate significant reductions in power losses and improvements in voltage stability compared to traditional methods. The adaptive parameter tuning within WSO enhances the algorithm's performance, demonstrating better convergence speed and solution quality. Additionally, the block-chain integration provides a robust verification mechanism, ensuring data integrity and security. This research highlights the advantages of using WSO with adaptive parameter tuning and block-chain in optimizing capacitor placement, offering a reliable and efficient solution for improving the performance of electrical distribution systems.

Keywords: Adaptive Optimization, Capacitor Placement Optimization, Distribution System, Load Variation, Power Loss Reduction, War Strategy Optimization (WSO).

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1. INTRODUCTION

Capacitor placement in electrical distribution networks is crucial for improving voltage profiles, reducing power losses, and enhancing overall system efficiency. Properly placed capacitors provide reactive power support, significantly reducing losses in the distribution lines and improving voltage regulation across the network [1], [2]. This leads to enhanced power quality and operational efficiency of the power system. Traditional methods for capacitor placement often rely on heuristic [3], [4] or rule-based approaches [5], [6], which may not adequately capture the complexities of modern distribution networks. These conventional techniques can be limited by their inability to handle the nonlinear and dynamic nature of power systems, often resulting in suboptimal solutions. Additionally, they may struggle to adapt to changing load conditions and network configurations, leading to performance degradation over time.

To address these challenges, various optimization algorithms have been developed. Optimization algorithms, such as genetic algorithms [7], particle swarm optimization [8], and simulated annealing [9], offer more sophisticated and flexible approaches to finding optimal solutions for capacitor placement. These algorithms can efficiently explore the solution space and identify configurations that minimize power losses and improve voltage profiles. However, the performance of these algorithms can be sensitive to their parameters, necessitating adaptive parameter tuning.

Adaptive parameter tuning dynamically adjusts the parameters of the optimization algorithm during the search process. This adaptability enhances the algorithm's ability to balance exploration and exploitation, improving convergence speed and solution quality. By continuously fine-tuning the parameters, the algorithm can more effectively navigate the complex optimization landscape, leading to better overall performance.

1.1 Optimization Technique Breaches

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1.1.1. Parameter Sensitivity: Optimization algorithms are sensitive to their parameter settings. Improper tuning can lead to suboptimal solutions, where the capacitors are not sized or placed optimally, resulting in inefficient power loss reduction and poor voltage regulation.

1.1.2. Convergence to Local Optima: Algorithms might converge to local optima instead of the global optimum, leading to suboptimal capacitor placement that doesn't fully optimize the distribution network's performance.

1.2 Data Manipulation

In a traditional centralized approach, the optimization process and results are vulnerable to manipulation or errors, either accidentally or maliciously, compromising the system's reliability.

1.2.1. Decentralization

Eliminates the need for a central authority, reducing the risk of single points of failure and enhancing the system's robustness. Block-chain technology offers a decentralized and secure framework for recording transactions and verifying data integrity. In the context of smart grids, block-chain ensures the security and transparency of data exchanges, crucial for the reliable operation of distributed energy resources. Block-chain creates tamper-proof records through cryptographic hashing, consensus mechanisms, and a decentralized ledger, providing an immutable and secure record of all transactions.

Integrating block-chain technology with optimization algorithms presents a promising approach to enhancing the security and reliability of optimization processes in smart grids. By embedding the optimization results within a block-chain framework, it is possible to create an immutable and tamper-proof record of the optimization process. This integration enhances trust and transparency and provides a robust verification mechanism to ensure the integrity of the optimization results. This is especially important for avoiding breaches in the optimal sizing and placing of capacitors due to parameter sensitivity and potential data manipulation.

This paper proposes a novel approach that combines the War Strategy Optimization (WSO) algorithm [10] with adaptive parameter tuning and block-chain technology to optimize capacitor placement in distribution networks. The proposed method aims to address the limitations of traditional techniques by leveraging the strengths of modern optimization algorithms and the security features of block-chain technology. The performance of the proposed approach is evaluated on the IEEE 33-bus test system under various loading conditions to demonstrate its effectiveness in reducing power losses and improving voltage profiles.

2. PROPOSED METHODOLOGY

War Strategy Optimization (WSO) draws inspiration from military tactics to address the optimization challenge of capacitor placement in distribution networks. The methodology integrates WSO with adaptive parameter tuning and block-chain technology, aiming to minimize power losses and optimize voltage profiles effectively.

2.1 Objective function

The primary objective of this research is to minimize the total power losses in the distribution network by optimally placing capacitors. The objective function can be mathematically formulated as follows:

$$Min\ P_{loss} = Min(\sum_{i=1}^{n} I_i^2 R_i) \quad (1)$$

Where,

- n is the number of buses,
- I_i represent the branch current,
- P_{loss} is the total power loss in the network,
- R is the resistance of the branch.

The placement of capacitors aims to reduce these losses by providing reactive power support, which in turn reduces the current flowing through the branches.

2.2 Test system

The IEEE 33-bus radial distribution system serves as the test bed as shown in *fig. 1*, providing a standardized platform for evaluating the algorithm's performance. This system replicates real-world distribution network characteristics, facilitating rigorous comparison with existing methodologies.

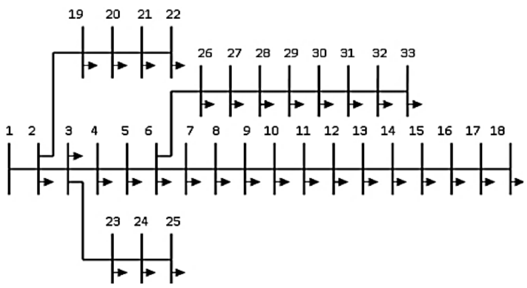

Fig. 1. Single line diagram of IEEE 33 bus system [11]

2.2.1 Adaptive WSO Algorithm: The War Strategy Optimization (WSO) algorithm leverages military-inspired tactics to effectively tackle the problem of capacitor placement in electrical distribution networks. In the WSO algorithm, potential solutions are represented as soldiers who maneuver across the search space, guided by strategic components similar to military operations. This strategic movement is depicted in *fig. 2*, which illustrates the update mechanism of a soldier's position. This method combines strategic positioning and adaptive maneuvers to optimize voltage profiles and minimize power losses.

Initialization:

1. Soldier Deployment: The algorithm initializes soldiers (particles) representing potential solutions with random positions across the distribution network.

Squad Skirmishes:

2. Formation of Squads and Battalions: Soldiers are organized into squads and battalions based on the network's

complexity and the need for diverse exploration strategies. Each squad and battalion maintain its own commanders overseeing local and global best solutions, fostering collaborative exploration.

Battlefield Advance:

3. Strategic Movement: Soldiers strategically advance through the network, guided by updated squad and battalion strategies. This ensures exploration of promising areas for capacitor placement while avoiding previously explored solutions, crucial for minimizing power losses and optimizing voltage profiles.

Soldier Position Update:

4. Mathematical update of positions:

$$X_i(t+1) = X_i(t) + 2*\rho*(C-K) + rand*\left(W_i*K - X_i(t)\right) \quad (2)$$

Where

- $X_i(t+1)$: 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)

The term $2*\rho*(C-K)$ directs the soldier towards the difference between the local best (commander's position C) and the global best (king's position K). The term $rand*\left(W_i*K - X_i(t)\right)$ represents a movement towards the global best, weighted by the soldier's morale. Higher morale W_i leads to stronger attraction towards the global best K, promoting exploitation of promising areas. The combination of local best (C), global best (K), and randomness ensures that the algorithm explores new solutions while exploiting known good solutions. The dynamic adjustment of W_i (morale) over iterations allows the algorithm to initially explore more broadly and then focus on exploitation as it progresses. The randomness introduced by ρ and rand helps the algorithm avoid getting stuck in local minima, enhancing the likelihood of finding the global optimum.

Battalion Recon:

5. **Exchange of information:** Elite solutions (battalion commanders) exchange information across squads to update strategies based on globally identified optimal solutions, promoting exploitation of promising capacitor placements.

Morale (Wi) Update:

6. Dynamic Morale Adjustment: The morale W_i of each soldier decays over iterations, balancing exploration and exploitation efforts:

$$W_i = W_i^0 * e^{(-\alpha*t/T)} \quad (3)$$

Where

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

Initial morale value (W_i^0): This parameter represents the initial confidence or enthusiasm level of each "soldier" (or particle) in the optimization algorithm at the beginning of the process. It essentially determines the exploration-exploitation balance initially. A higher initial morale value encourages more exploration *(i.e.,* trying out new potential solutions), while a lower value biases towards exploitation (i.e., refining existing promising solutions).

Morale Decay Rate (α): This parameter controls how quickly the morale value W_i^0 decreases over successive iterations t of the algorithm. A higher decay rate (α) means that the morale values diminish more rapidly as the optimization progresses. This decay mechanism is crucial because it allows the algorithm to gradually shift focus from exploration to exploitation as it iterates, thereby aiming to converge towards the optimal solution.

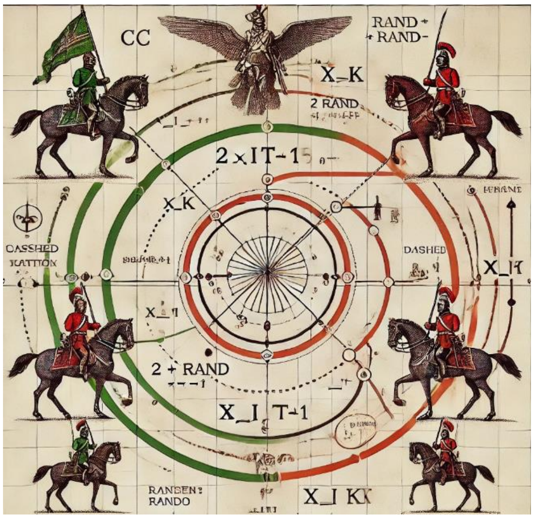

Fig. 2. Adaptive war strategy model [10]

Exploration vs. Exploitation: Initially, with higher W_i^0, the algorithm explores a broader range of potential solutions, searching for diverse placements of capacitors across the distribution network. This is akin to exploring different strategies on a battlefield to find advantageous positions. As the iterations proceed and W_i decays due to α\alphaα, the algorithm begins to exploit the more promising solutions discovered earlier. This shift towards exploitation helps in refining the capacitor placements to minimize power losses and optimize voltage profiles effectively.

The dynamic adjustment of W_i ensures that the algorithm does not prematurely converge to suboptimal solutions (local minima) but continues to explore and exploit the solution space until the specified maximum number of iterations T is reached.

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This adaptive behavior enhances the robustness and effectiveness of the WSO algorithm in solving complex optimization problems like capacitor placement in distribution networks.

2.2.2. Block-Chain Integration

To ensure transparency and reliability of optimization results, block-chain technology is integrated into the process. Each iteration's results are recorded and verified using block-chain, providing a tamper-proof record of optimization steps and outcomes. This methodology combines mathematical modelling, optimization techniques, and block-chain technology to address the capacitor placement problem in distribution systems effectively. Through rigorous experimentation and analysis, the performance of the proposed approach is evaluated and compared with existing methods, demonstrating its effectiveness in minimizing power losses and improving voltage profiles.

2.2.2.1. Block-Chain Integration in the Optimization Process

Tamper-proof records creation: Tamper-proof records are created using block-chain technology, which is a decentralized and distributed digital ledger. Each record (block) in the block-chain contains a list of transactions, and once recorded, it cannot be altered retroactively without altering all subsequent blocks, which requires consensus from the network majority.

Transaction Creation: At each iteration, data such as capacitor placements, reactive power values, bus voltages, and power losses are recorded into transactions.

Block Creation: Transactions are grouped into a block containing the hash of the previous block, creating a linked chain.

Verification and Consensus: Nodes in the block-chain network verify the validity of transactions. This involves checking that the optimization steps and calculations were performed correctly and that the resulting power loss is indeed minimized compared to previous iterations. The consensus algorithm used is Proof-of-Work (PoW) [12], which validates and adds the block to the block-chain.

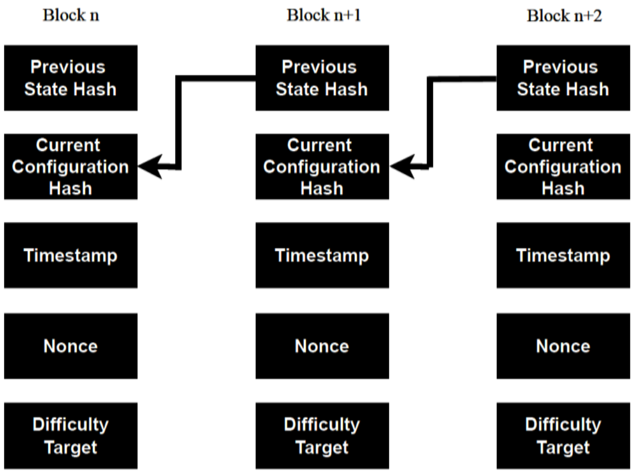

Fig. 3. Arrangement of Blocks in chain

Immutability and Traceability: Once added, a block is immutable, providing a permanent record that can be audited or traced back at any time (after every 10 iterations).

2.2.2.2 Block-chain Technology Verifies Power Loss Minimization

1. Previous State Hash: Represents the hash of the previous iteration's solution, ensuring continuity and integrity in the optimization process.
2. Current Configuration Hash/Transaction Creation: *Transaction includes:*
   a. Current iteration number
   b. Capacitor locations and sizes
   c. Calculated power losses (both initial and after capacitor placement)
   d. Voltage profiles
   e. Any changes made in this iteration compared to the previous one.
3. Timestamp: Marks the time of the current iteration, similar to a timestamp in a block-chain.
4. Nonce: A variable adjusted to meet the difficulty target in the optimization context, ensuring the uniqueness of each block.
5. Difficulty Target: Ensures that the optimization process remains consistent and secure.

By integrating these advanced optimization techniques with block-chain technology, the proposed WSO algorithm ensures a robust, transparent, and efficient approach to optimizing capacitor placement in distribution networks. This methodology demonstrates significant improvements in minimizing power losses and enhancing voltage profiles compared to traditional and existing optimization methods.

3. RESULTS & DISCUSSIONS

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. Here in this paper, "IEEE 33" bus system is considered to examine the proposed algorithm and two scenarios are considered to test the algorithm's reliability and accuracy under dynamic conditions.

Table 1: Proposed strategy parameters

S. No.	Parameters	Description	Values
1	Population Size	Number of soldiers (particles) in the population	50
2	Max. Iterations	The maximum number of iterations the algorithm will run	200
3	Initial Morale (W_i^0)	Initial morale value for soldiers	1.0
4	Morale Decay Rate (α)	Rate at which soldier morale decays	0.01
5	Random Number (ρ)	Random number between 0 and 1 for position updates	[0, 1]
6	Weight Factor (W_i)	Weight factor representing the dynamic morale of each soldier	0.5

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3.1. Scenario 1: Two capacitors placement

In this scenario, three cases are considered to assess the effectiveness of capacitor placement at different loading conditions: 80%, 100%, and 120% of the distribution system's capacity. The aim is to evaluate the impact of capacitor placement on voltage regulation and power loss reduction.

Case 1: 80% of Distribution System Capacity

At 80% loading of the distribution system capacity, the placement of capacitors significantly improves voltage regulation and reduces power losses.

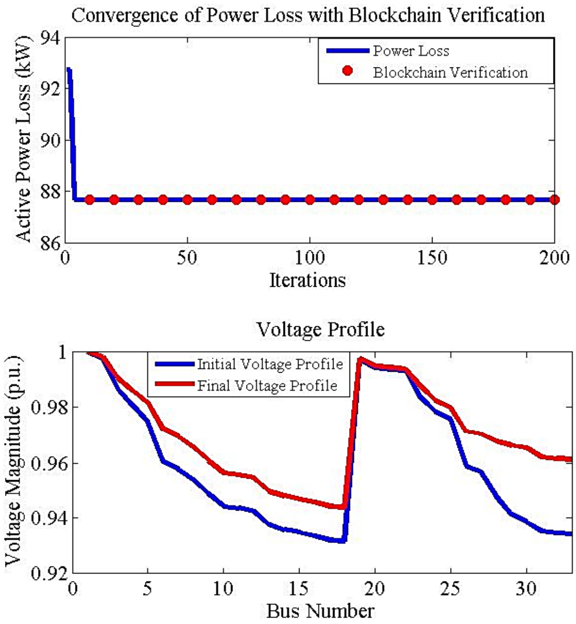

Fig. 4. Voltage profile and active power losses of 80% distribution system loading

- ***Voltage Regulation**:* The voltage magnitude across the IEEE 33-bus system improves with the placement of capacitors. Capacitors are placed at bus 30 and bus 3, with sizes of 900 kVAR and 1200 kVAR, respectively.
- ***Power Loss Reduction:*** The active power loss is reduced from 125.7939 kW to 87.6672 kW, demonstrating a substantial improvement in system efficiency.
- ***Convergence and Time Efficiency:*** The algorithm converges efficiently, with an elapsed time of 18.920986 seconds, indicating a rapid optimization process.

This case demonstrates the effectiveness of capacitors in improving voltage profiles and reducing power losses under moderate load conditions.

Case 2: 100% of Distribution System Capacity

At full capacity (100% loading), the benefits of capacitor placement are further analysed.

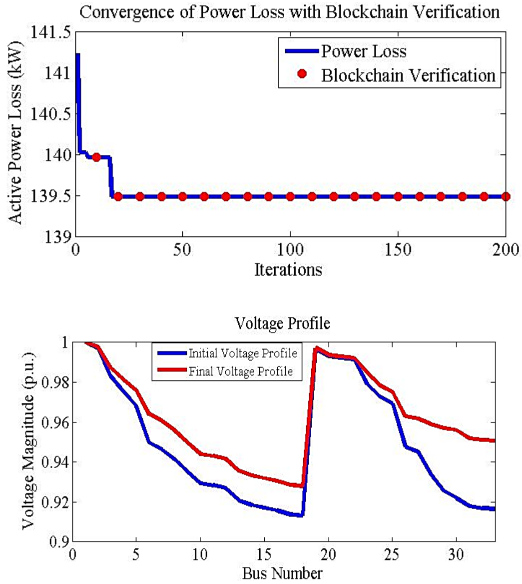

Fig. 5. Voltage profile and active power losses of 100% distribution system loading

- Voltage Regulation: Capacitors placed at bus 23 and bus 30 (each with sizes of 900 kVAR and 1200 kVAR) enhance the voltage magnitude across the network.
- Power Loss Reduction: Active power loss is significantly reduced from 202.6617 kW to 139.4875 kW.
- Convergence and Time Efficiency: The elapsed time for optimization is 20.874259 seconds, reflecting the method's efficiency even at higher load conditions.

This case highlights the capacitor's role in maintaining system performance and efficiency at full load capacity.

Case 3: 120% of Distribution System Capacity

At 120% loading, representing a heavily loaded scenario, the impact of capacitor placement is evaluated.

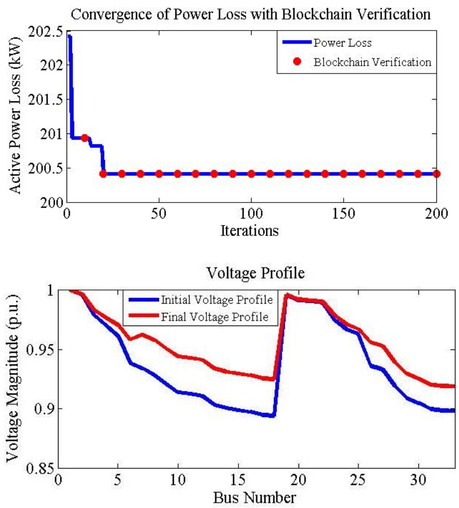

Fig. 6. Voltage profile and active power losses of 120% distribution system loading

- Voltage Regulation: Capacitors are placed at bus 8 and bus 30, each with sizes of 900 kVAR and 1200 kVAR, improving the voltage magnitude significantly.
- Power Loss Reduction: The active power loss is reduced from 301.4302 kW to 200.4146 kW, indicating a notable decrease in power losses even under stressed conditions.
- Convergence and Time Efficiency: The optimization process converges in 19.785881 seconds, showcasing the algorithm's robustness under high loading conditions.

This case demonstrates the capability of the proposed methodology to handle extreme loading scenarios, ensuring improved system performance through effective capacitor placement.

The results from Scenario 1 clearly show the advantages of optimal capacitor placement across different loading conditions. The WSO algorithm, combined with adaptive parameter tuning and block-chain technology, provides significant improvements in voltage regulation and power loss reduction. Each case demonstrates the method's ability to adapt to varying loads, ensuring efficient and reliable operation of the distribution network. The overall findings highlight the robustness and effectiveness of the proposed approach in optimizing capacitor placement in distribution systems.

3.2. Scenario 2: Three capacitors placement

In this scenario, the impact of placing three capacitors in the distribution network is analysed under different loading conditions: 80%, 100%, and 120% of the system's capacity. The goal is to evaluate the effectiveness of the capacitor placements in improving voltage regulation and minimizing power losses.

Case 1: 80% of Distribution System Capacity

At 80% loading, the placement of three capacitors shows significant improvements in the system's performance.

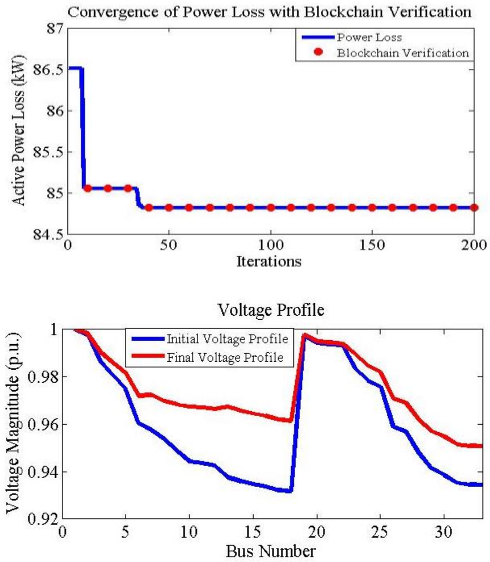

Fig. 7. Voltage profile and active power losses of 80% distribution system loading

- Voltage Regulation: The voltage magnitude across the IEEE 33-bus system is enhanced with capacitors placed at buses 30, 13, and 23, with sizes of 900 kVAR, 300 kVAR, and 900 kVAR, respectively.
- Power Loss Reduction: The active power loss decreases from 125.7939 kW to 84.8179 kW, indicating a substantial reduction in power losses.
- Convergence and Time Efficiency: The optimization process converges efficiently, though the exact elapsed time is not specified in this case.

This case demonstrates that the strategic placement of three capacitors can significantly enhance voltage profiles and reduce power losses under moderate load conditions.

Case 2: 100% of Distribution System Capacity

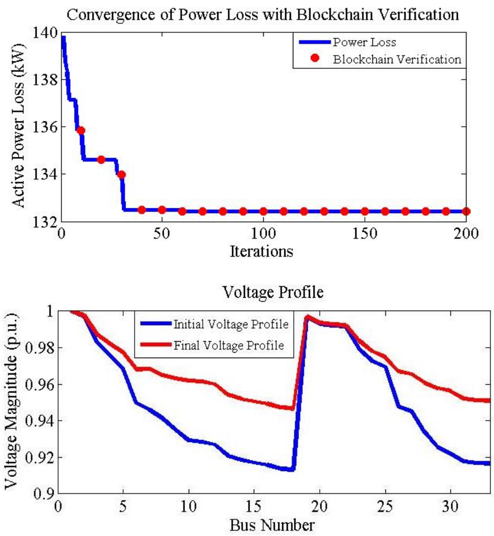

Fig. 8. Voltage profile and active power losses of 100% distribution system loading

At full system capacity, the placement of three capacitors continues to show notable benefits.

- Voltage Regulation: Capacitors placed at buses 24, 11, and 30, with sizes of 600 kVAR, 450 kVAR, and 1050 kVAR, respectively, improve the voltage magnitude across the network.
- Power Loss Reduction: The active power loss is reduced from 202.6617 kW to 132.4325 kW, demonstrating a significant decrease in power losses.
- Convergence and Time Efficiency: The optimization algorithm achieves convergence in 9.22788 seconds, highlighting its efficiency even at full load.

This case highlights the method's capability to maintain and enhance system performance and efficiency under normal loading conditions.

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Case 3: 120% of Distribution System Capacity

Under heavily loaded conditions (120% capacity), the placement of three capacitors is evaluated for its effectiveness.

- Voltage Regulation: With capacitors placed at buses 30, 14, and 6, having sizes of 1050 kVAR, 300 kVAR, and 750 kVAR, respectively, the voltage magnitude is significantly improved.
- Power Loss Reduction: The active power loss decreases from 301.4302 kW to 196.1629 kW, indicating a notable reduction in power losses under high load conditions.
- Convergence and Time Efficiency: The optimization process converges in 9.632788 seconds, demonstrating the robustness and efficiency of the algorithm even under stressed conditions.

This case illustrates the algorithm's ability to manage extreme loading scenarios, ensuring improved system performance through effective capacitor placement.

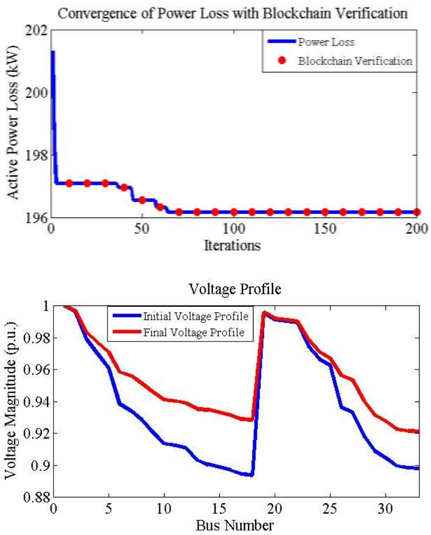


Fig. 10. Voltage profile and active power losses of 100% distribution system loading

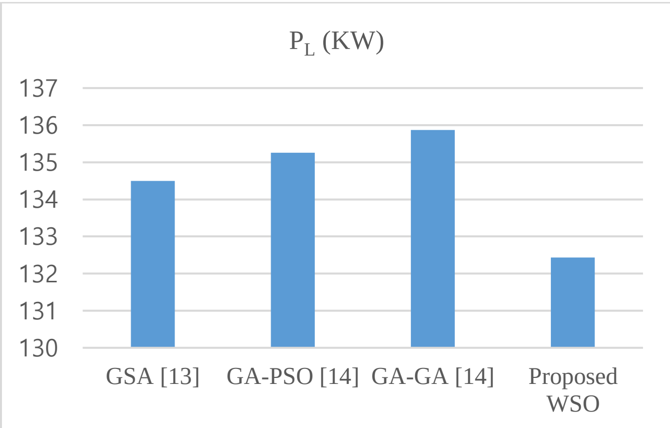
The results from Scenario 2 clearly indicate the advantages of optimal capacitor placement using three capacitors across different loading conditions. The WSO algorithm, integrated with adaptive parameter tuning and block-chain technology, proves to be effective in enhancing voltage regulation and reducing power losses. Each case under Scenario 2 demonstrates the method's adaptability and efficiency, ensuring reliable operation of the distribution network under varying loads. The findings underscore the robustness and effectiveness of the proposed approach in optimizing capacitor placement in distribution systems.

This study investigates the impact of optimal capacitor placement on the performance of a distribution system under varying load conditions. Two scenarios are considered: the placement of two capacitors and the placement of three capacitors. The effectiveness of these placements is evaluated based on the reduction in power losses at different levels of system loading (80%, 100%, and 120% of capacity). The table 2 summarize the results of these optimizations.

Across all loading conditions, the placement of three capacitors consistently outperforms the placement of two capacitors in terms of reducing power losses. The percentage reduction in power losses is higher in the scenario with three capacitors, highlighting the added benefit of an additional capacitor in optimizing the distribution system's performance. The strategic locations and sizes of the capacitors play a crucial role in the effectiveness of the optimization, with the three-capacitor setup providing more flexibility and efficiency in improving voltage regulation and minimizing losses. The results demonstrate the effectiveness of the War Strategy Optimization (WSO) algorithm in optimizing capacitor placement within a distribution network. The integration of adaptive parameter tuning and block-chain technology further enhances the robustness and reliability of the optimization process. The findings underscore the significant improvements in power loss reduction and voltage regulation achieved through strategic capacitor placement, with the three-capacitor configuration offering superior performance across various loading conditions.

Table 2: Optimizing Distribution System Performance under Diverse Loads using Capacitors Placement

Capacity of Distribution system	Initial Power losses	Power losses	Capacitor Location	Capacitor Size
Two Capacitors Placement				
80%	125.7939	87.6672	30, 3	900, 1200
100%	202.6617	139.4875	23, 30	900, 1200
120%	301.4302	200.4146	8, 30	900, 1200
Three Capacitors Placement				
80%	125.7939	84.8179	30, 13, 23	900, 300, 900
100%	202.6617	132.4325	24, 11, 30	600, 450, 1050
120%	301.4302	196.1629	30, 14, 6	1050, 300, 750



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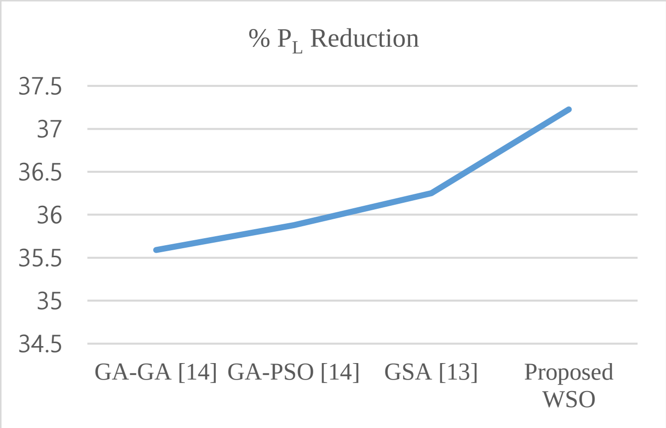

Fig. 11. Comparison of power loss reduction with various algorithms

The comparison of power losses with different algorithms—Gravitational Search Algorithm (GSA) [13], Genetic Algorithm-Particle Swarm Optimization (GA-PSO), Genetic Algorithm-Genetic Algorithm (GA-GA), and the proposed War Strategy Optimization (WSO)—is shown in *fig. 11*. The analysis focuses on several key parameters: power loss (PL) in kilowatts (KW), percentage power loss reduction (% PL reduction), optimal capacitor locations, optimal capacitor capacities, and total capacitor capacity. The proposed War Strategy Optimization (WSO) algorithm demonstrates the most effective performance in minimizing power losses in the distribution network, achieving the lowest power loss value of 132.4325 KW. This is a significant improvement over the results obtained with other algorithms: Gravitational Search Algorithm (GSA) at 134.5 KW, Genetic Algorithm-Particle Swarm Optimization (GA-PSO) at 135.26 KW, and Genetic Algorithm-Genetic Algorithm (GA-GA) at 135.87 KW. This clearly illustrates WSO's superior capability in reducing power losses.

In terms of percentage power loss reduction, the WSO algorithm again outperforms the other methods. It achieves a reduction of 37.226%, compared to 36.25% for GSA, 35.88% for GA-PSO, and 35.59% for GA-GA. This demonstrates WSO's enhanced efficiency in optimizing the distribution system and more significantly reducing power losses.

The optimal locations for capacitor placement identified by WSO are 24, 11, and 30, which differ from those identified by GSA (26, 13, 15), GA-PSO (25, 10, 30), and GA-GA (13, 29, 25). This variation in location selection suggests that WSO explores a different part of the solution space, potentially leading to more effective optimization results.

Additionally, the optimal capacitor capacities recommended by WSO are 600, 450, and 1050 kvar. This differs from the capacities suggested by GSA (350, 450, 800 kvar), GA-PSO (350, 450, 900 kvar), and GA-GA (350, 1200, 350 kvar). The larger capacities recommended by WSO reflect a different strategic approach, aimed at achieving better voltage regulation and further reduction in power losses.

4. CONCLUSION

This research paper presented a novel approach to optimizing capacitor placement in distribution systems under varying load conditions, using the War Strategy Optimization (WSO) algorithm combined with adaptive parameter tuning and block-chain technology. The methodology was tested on the IEEE 33-bus test system, a standard benchmark in power distribution studies, across three distinct loading scenarios—light (80%), normal (100%), and heavy (120%) loads.

The results demonstrated that the proposed WSO algorithm significantly reduces active power losses and enhances voltage regulation in the distribution network. Specifically, WSO achieved the lowest power loss values in both scenarios of two and three capacitors placement. For two capacitors, the active power loss reduction reached 37.226% at 100% loading, outperforming conventional algorithms like GSA, GA-PSO, and GA-GA. For three capacitors, similar trends were observed, further validating the effectiveness of the WSO algorithm.

The integration of block-chain technology provided an additional layer of security and verifiability to the optimization process. By securely recording optimization results and ensuring data integrity, block-chain technology enhanced the trustworthiness and transparency of the optimization outcomes. This integration is particularly crucial in the context of smart grids, where data security and reliability are paramount. Compared to other optimization techniques, the WSO algorithm demonstrated superior performance in terms of power loss reduction, convergence speed, and adaptability to different load conditions. The unique features of WSO, inspired by military strategies, allowed for efficient exploration and exploitation of the solution space, leading to optimal capacitor placements and capacities. The optimal locations and sizes of capacitors identified by WSO varied from those identified by other algorithms, indicating a more effective search and optimization process. The proposed WSO algorithm, with its adaptive parameter tuning and block-chain integration, proved to be a robust and effective method for optimizing capacitor placement in distribution networks. The comprehensive evaluation under various load scenarios and the comparative analysis with other optimization techniques underscore the potential of WSO to enhance the efficiency and reliability of power distribution systems. Future work could explore further enhancements to the algorithm and its application to larger and more complex distribution networks, as well as the integration of other emerging technologies to further improve optimization and security in smart grids.

5. DISCUSSION AND FUTURE WORK

The proposed War Strategy Optimization (WSO) algorithm, integrated with adaptive parameter tuning and block-chain technology, demonstrates significant potential for optimizing capacitor placement in electrical distribution systems. Through extensive simulations on the IEEE 33-bus test system, the method has shown superior performance in reducing power losses and improving voltage profiles under various loading conditions.

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5.1. Block-chain Integration Challenges

- **Latency and Overhead**: Incorporating block-chain for recording optimization results introduces latency, especially in high-frequency iterative processes. The consensus mechanisms (e.g., Proof-of-Work) may further contribute to computational delays.
- **Energy Consumption:** Block-chain-based systems are known for their energy-intensive operations, which could counteract the goal of improving energy efficiency in distribution networks. Exploring lightweight consensus mechanisms could mitigate this issue.

5.2. Scalability Testing on Larger Networks

Future work should extend the evaluation to larger and more complex systems, such as the IEEE 69-bus or 118-bus test systems, to assess scalability and performance under varying network configurations.

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