# APPLICATION OF SHUNT CAPACITOR FOR BUS VOLTAGE ENHANCEMENT IN DISTRIBUTION SYSTEM USING CUCKOO SEARCH ALGORITHM COMPARED WITH BAT ALGORITHM BY DECREASING THE POWER LOSSES

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**Abstract**

**Aim:** This work proposes a comparative analysis of two algorithms named a novel Cuckoo Search Algorithm (CSA) and a Bat Algorithm (BA) for enhancing the bus voltage in the Distribution Network by optimal allocation of a shunt capacitor.

**Materials and Methods:** Novel Cuckoo Search Algorithm and Bat Algorithm are utilized for optimal location and sizing of shunt capacitors in the radial distribution system. The sample size is calculated using Gpower for two groups and there are 14 samples used in this work. The G power is taken as 0.8.

**Results:** Based on the results obtained CSA produces better results than BA in terms of bus voltage enhancement. The significant value obtained is 0.001 ($p<0.05$) which is statically significant.

**Conclusion:** CSA-based optimization method provides significantly better bus voltage enhancement (0.9507 p.u) than BA-based method (0.9469 p.u).

**Keywords:** Novel Cuckoo Search Algorithm, Bat Algorithm, Bus Voltage, Radial Distribution System, Power Loss Reduction, Shunt Capacitor, Power Systems.

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## 1. Introduction

Optimizing the reactive power injection is an important aspect of the electric power system's economical and safe operation. Reasonable distribution of reactive compensation capacity in the form of switched capacitor banks, static var controllers is the pre-condition of realizing voltage and reactive VAR controlling. It can reduce the power loss, improve the power factor and improve the bus voltage quality, and is helpful for improving the stability of the power systems (Mahmoud and AL-Sunni 2015). The aim of this research is to enhance the bus voltage using a shunt capacitor in the distribution system (Thangaraj Yuvaraj et al. 2021). This present approach can be implemented in the real-time distribution of power systems and Indian sub-distribution systems (T. Yuvaraj, Devabalaji, and Thanikanti 2020); (Ghatak, Sannigrahi, and Acharjee 2018).
From the past 5 years, more than 400 articles were published in science direct and IEEE-Xplore with various objective functions. A hybrid optimization technique based on analytical and two heuristic methods is implemented to find the appropriate location and sizing of shunt capacitors into distribution networks with the objective of minimizing the total power loss and energy cost (Kalam et al. 2019). Various shunt compensators are utilized along with shunt capacitors for verifying the effectiveness of the TFWO algorithm in power loss reduction, enhancing the voltage profile (Eid and Kamel 2020). An efficient hybrid method is proposed to solve the allocation problem of capacitor banks in the radial distribution system (RDS) for power loss reduction (Upper, Hemeida, and Ibrahim 2017). A novel and efficient analytical closed-form expressions are proposed for the optimal allocation of multiple capacitors in distribution power systems to maximize the total cost reduction (CR) while considering power losses (Kalam et al. 2019). From the above, the hybrid optimization technique provides a better voltage profile and loss reduction than other methods (Kalam et al. 2019).
Our institution is passionate about high quality evidence based research and has excelled in various domains (Vickram et al. 2022; Bharathiraja et al. 2022; Kale et al. 2022; Sumathy et al. 2022; Thanigaivel et al. 2022; Ram et al. 2022; Jothi et al. 2022; Anupong et al. 2022; Yaashikaa, Keerthana Devi, and Senthil Kumar 2022; Palanisamy et al. 2022). In the previous research, the researchers have not considered bus voltage enhancement as an objective function in the shunt capacitor allocation problem and also failed to reduce the power losses effectively in the power systems. Hence a new technique has been proposed for bus voltage enhancement with considerations of power loss reduction. The aim of this research is to allocate the shunt capacitor optimally in a distribution system using CSA and BA for bus voltage improvement by reducing the power loss.

## 2. Materials and Methods

This study was conducted in a Power System Simulation Lab, Institute of Electrical and Electronics Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences. Two algorithms have been coded using the MATLAB Script and its sample size has been calculated using GPower software. It is determined that each algorithm has 7 samples and a total of 14 sample tests have been carried out (GPower 0.8). In this work, no human and animal samples were used so no ethical approval is required (P., C., and T. 2018); (Desu 2012).
Two algorithms namely the Novel Cuckoo Search Algorithm (CSA) and Bat Algorithm (BA) are used to determine the bus voltage using a shunt capacitor in the radial distribution power systems. The single line diagram of the shunt capacitor in the RDS is shown in Fig. 1. The optimal sizes of shunt capacitors are varied from 10% to 100% of total kVAr to obtain bus voltage. The voltage values are obtained by various sizing of the shunt capacitor. The obtained voltage values for shunt capacitor using BA and CSA for various locations and sizes have been tabulated along with power loss values for both the algorithms in Table 1.

**Cuckoo search algorithm**
Novel Cuckoo Search Algorithm (CSA) was introduced by (Yang and Deb 2009). It has two main operators. One is a direct search by Levy flights and another one is a random search based on the probability of host birds discovering an alien egg in the nest. It consists of the following 3 steps:
***Step 1:*** Every cuckoo lays one egg at a time and dumps its egg in a randomly chosen nest.
***Step 2:*** The best nest with a high-quality egg will carry over to the next generation.
***Step 3:***. The number of host nests is fixed and the egg laid by a cuckoo is discovered by a host nest. The complete process is shown in Fig. 2.

**Bat Algorithm**
Bat algorithm (BA) was proposed by Yang based on the echolocation behaviour of bats (Xing and Gao 2014) It has mainly 8 steps i.e
***Step 1:*** Initializing bat population [such as($xi$) and velocities ($vi$)].

***Step 2:*** Initializing parameters, such as pulse frequency ($fi$), pulse rate ($ri$) and loudness parameters ($Ai$).
***Step 3:*** Evaluating bats in the initial population according to the fitness function.
***Step 4:*** Generating candidate bats through random flying and local search.
***Step 5:*** Evaluating candidate bats according to the fitness function.
***Step 6:*** Echolocation parameters update.
***Step 7:*** Rank the bats and find the current best $x*$.
***Step 8:*** Termination.
Steps (4-7) are employed in the same way until a termination criterion is met. The complete algorithm is given as a flowchart and shown in Fig. 3.

**Statistical Analysis**
Independent t-test analysis is carried out using the SPSS (Rosius and Redbooks 2016) system and its mean and standard deviation is analyzed. The independent variable is the size and location of the shunt capacitor and the dependent variable is voltage values. Two independent group analysis tests are carried out to calculate the bus voltage of both algorithms.

## 3. Results

Figure 4 shows the comparison of the voltage of each bus of the IEEE 34- bus system before and after placement of the shunt capacitor in the RDS. The graph ensures that the bus voltage profile values are enhanced after placing the shunt capacitor in the distribution system.
Table 2 represents the performance analysis results of the shunt capacitor using CSA and BA. CSA (160.05kW & 0.9507p.u) provides better power loss reduction and bus voltage enhancement than BA (165.90kW & 0.9469p.u). From the results, we can conclude that CSA-based optimization provides better performance than BA-based optimization techniques in terms of loss reduction and bus voltage improvement.
Table 3 represents the T-test comparison of CSA and BA algorithms for various sizes and bus voltage values. CSA (Mean value of 0.950657) based optimization produces better bus voltage enhancement than BA (Mean value of 0.923957). The standard error mean value for CSA is (0.0002299) which is better than BA (0.0026857).
Table 4 represents the independent samples test for CSA and BA. The t value and mean difference value for CSA are (26.207 & 12) and BA are (26.207 & 6.088). There is a significant difference between the two groups since p (0.001) is less than 0.05.

Figure 5 depicts the comparison chart of CSA and BA algorithms in terms of mean voltage. CSA(≈0.9507p.u) produces better bus voltage enhancement than BA(≈0.9469p.u).

## 4. Discussions

Two algorithms CSA and BA were implemented to test the present approach. From the obtained results CSA-based optimization method provides significantly better bus voltage enhancement (0.9507 p.u) than the BA-based method (0.9469 p.u).
In the radial distribution system, shunt capacitors are located at optimal locations for the improvement of voltage profile and to mitigate power losses. It is essential to determine the optimal sitting and sizing of capacitors required to maintain a nominal voltage profile and to reduce the feeder losses. Various techniques have been implemented for shunt capacitor allocation problems with different objective functions. CSA and PSO algorithms have been implemented for shunt capacitor allocation problems with an objective function of power loss mitigation. CSA (33.34%) provides better power loss reduction than PSO (23.71%) (Cholapandian, Yuvaraj, and Devabalaji 2021). An integrated approach is proposed to find the optimal location and sizing of the capacitor to minimize power losses and voltage profile of the system using the CSA and Heuristic method. From the results, it is observed that CSA (27.6% & 0.9533 p.u) provides better loss mitigation and voltage profile enhancement than Heuristic method (24.53% & 0.9515 p.u) (Devabalaji, Yuvaraj, and Ravi 2018). CSA and PSO were implemented in IEEE 69 bus system for net savings. From the obtained results CSA based optimization technique produced a net savings of $33494.90 which is better than PSO-based net savings of $29301.00 (El-Fergany and Abdelaziz 2014). A two-stage methodology of finding the optimal locations and sizes of shunt capacitors for reactive power compensation of RDS using BA for various test systems with an objective function of annual cost savings. The annual cost savings for IEEE 15, 33 & 34 test systems using BA are $ 13,398 $ 38,678 and $ 25,713 respectively (Eltamaly and Abdelaziz 2019).
Due to the larger size of capacitor in the RDS, IDME based optimization provides better bus voltage (0.9420 p.u) than CSA (0.9301 p.u) (Thangaraj Yuvaraj et al. 2021). Flower pollination optimization algorithm and power loss index produce a better voltage value of 0.9676 p.u than the BA-based optimization technique (Hajiabbas and Mohammadi-Ivatloo 2020). From the existing literature survey, only a few articles ensure that the

IDME and FPOA algorithms provide better bus voltage improvement than CSA and BA. Even though IDME and FPOA provide better bus voltage improvement they fail to provide better energy saving and power loss reduction. So we can infer that CSA can be applied to the capacitor allocation problem to get better bus voltage enhancement in the distribution system.

The present work of capacitor allocation problem suffers from the disadvantage that it considers the load pattern over a period of time. In due the course of time this load pattern changes and so does the load forecast. Hence such a method of Static Var compensation using shunt capacitor banks suffers from an inherent drawback of not being able to supply required var with changing load pattern. Also, in this study, we have considered only static analysis with a shunt capacitor in the RDS. To avoid inherent issues in the future for capacitor allocation problems, the selection of those shunt capacitor banks that would contribute to a present var requirement without injecting excessive leading VAR ensures better control.

## 5. Conclusion

A novel CSA and BA have been implemented in the IEEE 34-Test system using a shunt capacitor to enhance the bus voltage in the RDS. From the obtained results CSA-based optimization method provides significantly better bus voltage enhancement (0.9507 p.u) than the BA-based method (0.9469 p.u). Independent T-test analysis reveals that the significance value is 0.001 ($p<0.05$) which is statistically significant.

**Declaration**

**Conflict of Interest**

No conflict of interest in this manuscript.

**Author Contributions**

Author PP was involved in data collection, data analysis, and manuscript writing. Author TY was involved in data validation and review of manuscripts.

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**Tables and Figures**

Table 1: Comparison of IEEE 34 bus simulation results using CSA and BA algorithms for various locations and sizes.

| S.No | Location | BA | | CSA | | BA | CSA |
|---|---|---|---|---|---|---|---|
| | | Size (kVAr) | Ploss (KW) | Size (kVAr) | Ploss (KW) | Vmin (p.u) | Vmin (p.u) |
| 1 | 10,18,25 | 2478 | 164.12 | 2459 | 160.05 | 0.9403 | 0.9508 |
| 2 | 9,17,24 | 2589 | 164.49 | 2540 | 160.19 | 0.9432 | 0.9506 |
| 3 | 10,17,25 | 2587 | 164.56 | 2525 | 160.26 | 0.9412 | 0.9509 |
| 4 | 11,18,25 | 2490 | 164.73 | 2442 | 160.23 | 0.9434 | 0.9508 |
| 5 | 8,16.23 | 2544 | 164.88 | 2512 | 162.58 | 0.9462 | 0.9502 |
| 6 | 12,17,24 | 2570 | 165.12 | 2508 | 160.50 | 0.9466 | 0.9506 |
| 7 | 12,17,25 | 2620 | 165.34 | 2510 | 160.96 | 0.9469 | 0.9507 |

Table 2: Performance analysis of IEEE-34 bus systems with CSA and BA

| Items | Base Case | BA | CSA |
|---|---|---|---|
| Optimal location & Size (kW) | - | 650 (10)<br>1150 (25) | 692(10)<br>980 (18)<br>787 (25) |
| Real power loss $P_L$(kW) | 221.286 | 165.9 | 160.05 |
| % of $P_L$ reduction | - | 25.02 | 27.67 |

| | | | |
|---|---|---|---|
| $V_{min}$ (p.u) | 0.9416 | 0.9469 | 0.9507 |

Table 3: Statistical analysis of CSA and BA algorithms. Mean Output voltage, Standard deviation and standard error values are obtained for 14 sample data sets. When compared, CSA has better performance than BA.

| **Group Statistics** | | | | | |
|---|---|---|---|---|---|
| **GROUP** | | **N** | **Mean** | **Std. Deviation** | **Std. Error Mean** |
| VOLTAGE MINIMUM | CSA | 7 | 0.950657 | 0.0002299 | 0.0000869 |
| | BA | 7 | 0.923957 | 0.0026857 | 0.0010151 |

Table 4: Independent sample T-test is performed for the two groups for significance and standard error determination. P-value (0.001) is less than 0.05 and it is considered to be statistically significant.

| **Independent Samples Test** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
| | | F | Sig | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference | |
| | | | | | | | | | Lower | Upper |
| **VOLTAGE MINIMUM** | Equal variances assumed | 21.530 | 0.001 | 26.207 | 12 | 0.000 | 0.0267000 | 0.0010188 | 0.0244802 | 0.0289198 |
| | Equal variances not assumed | | | 26.207 | 6.088 | 0.000 | 0.0267000 | 0.0010188 | 0.0242158 | 0.0291842 |

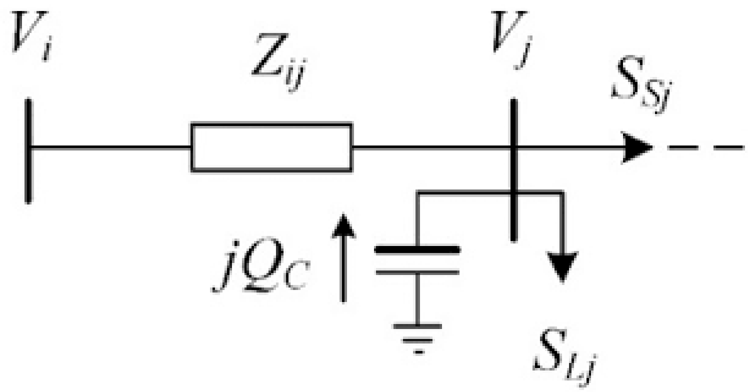

Fig. 1. Shunt Capacitor configuration in the distribution network

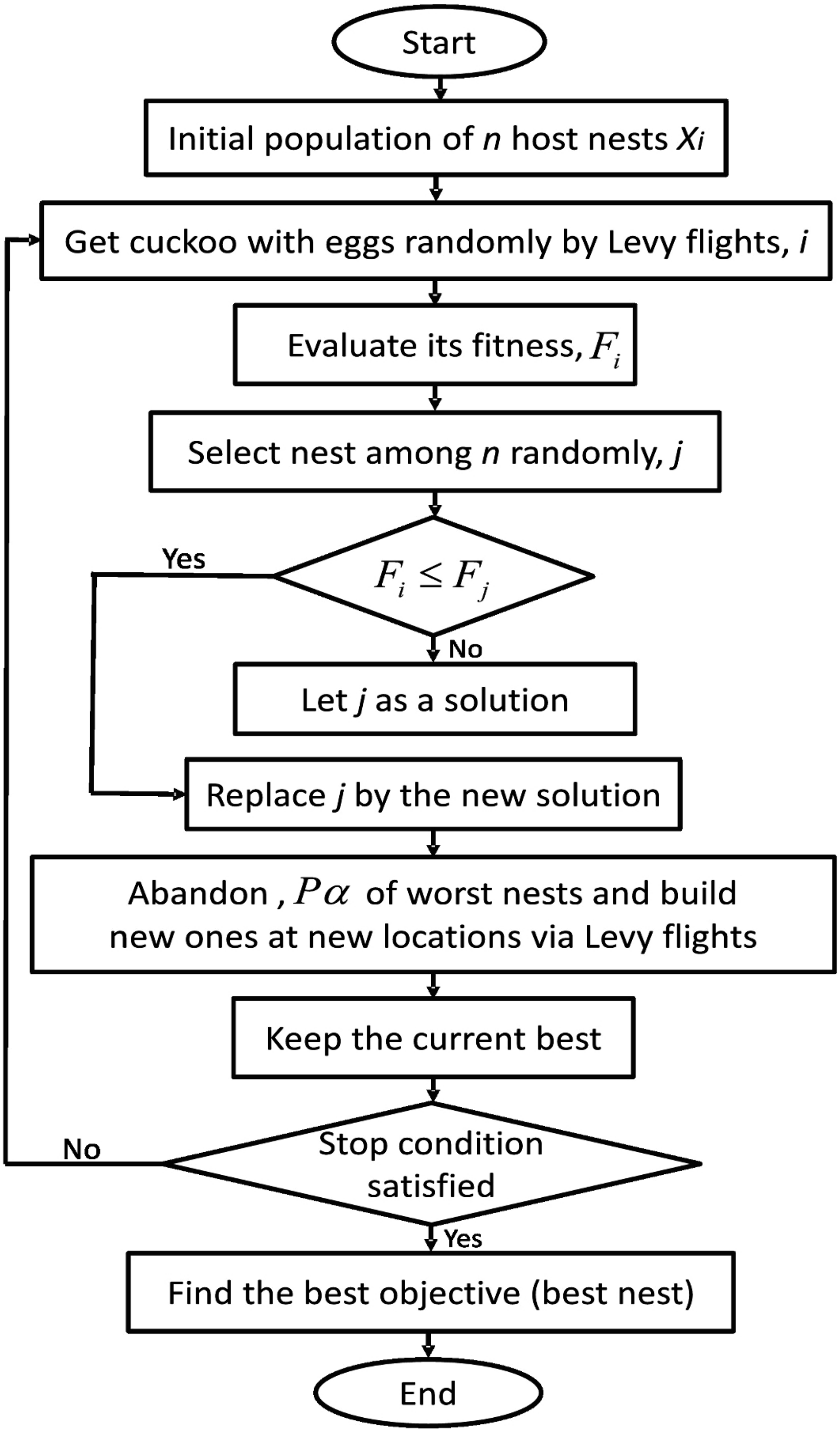


Fig. 2. Flow chart of Cuckoo Search Algorithm

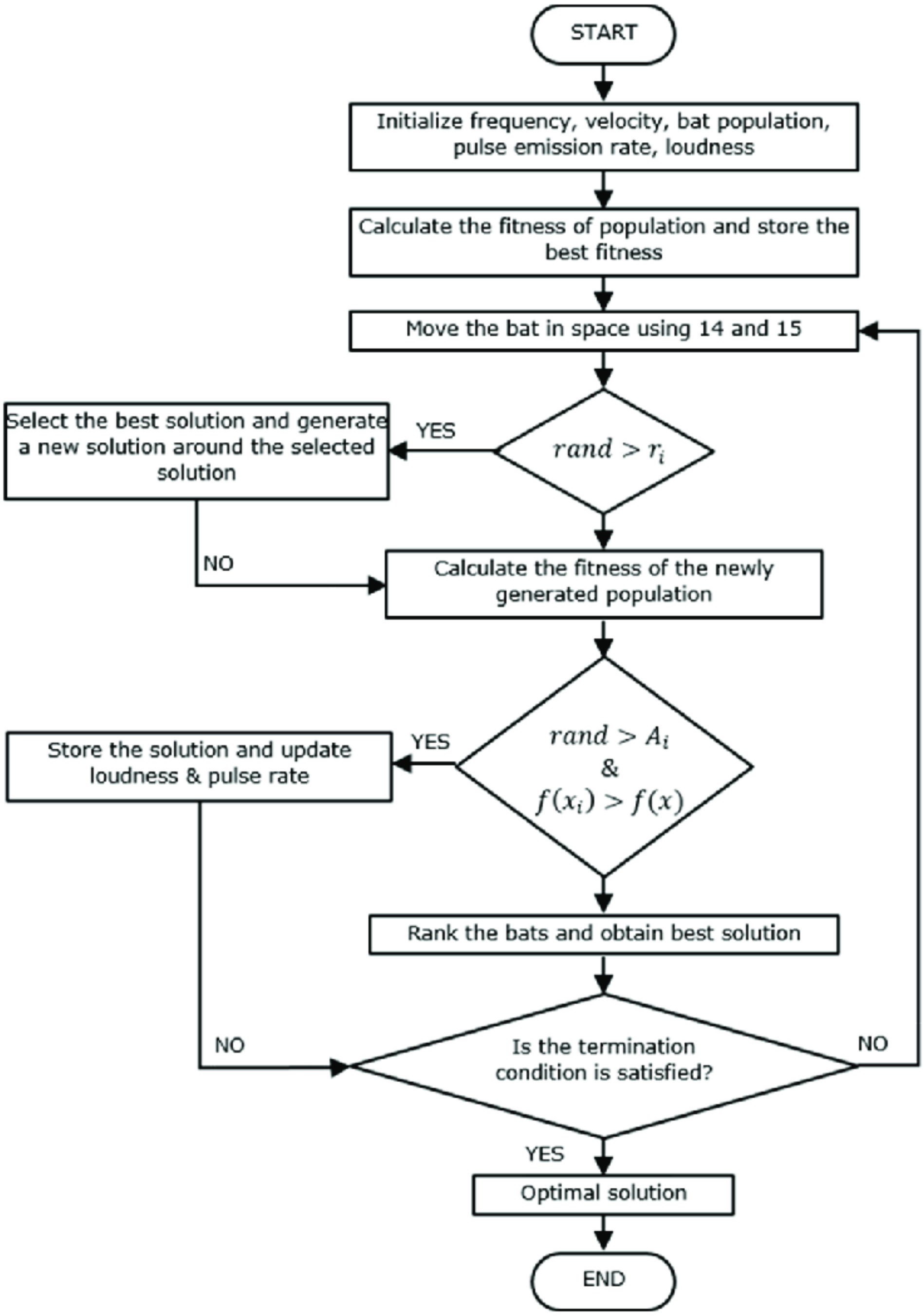


Fig. 3. Flow chart of Bat Algorithm

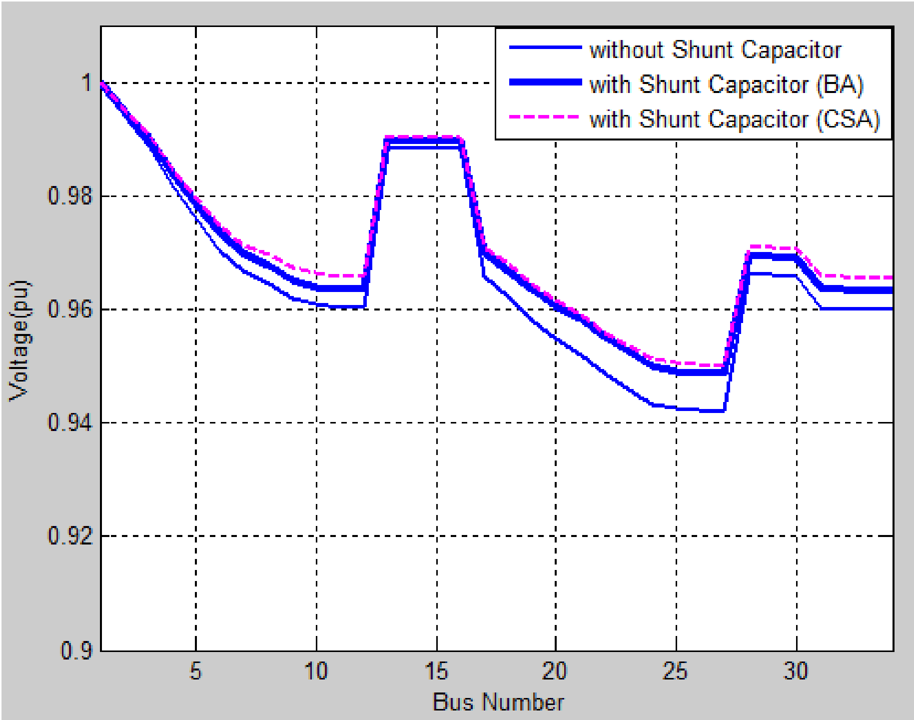


Fig. 4. Bus voltage profile of the systems with and without Shunt Capacitor

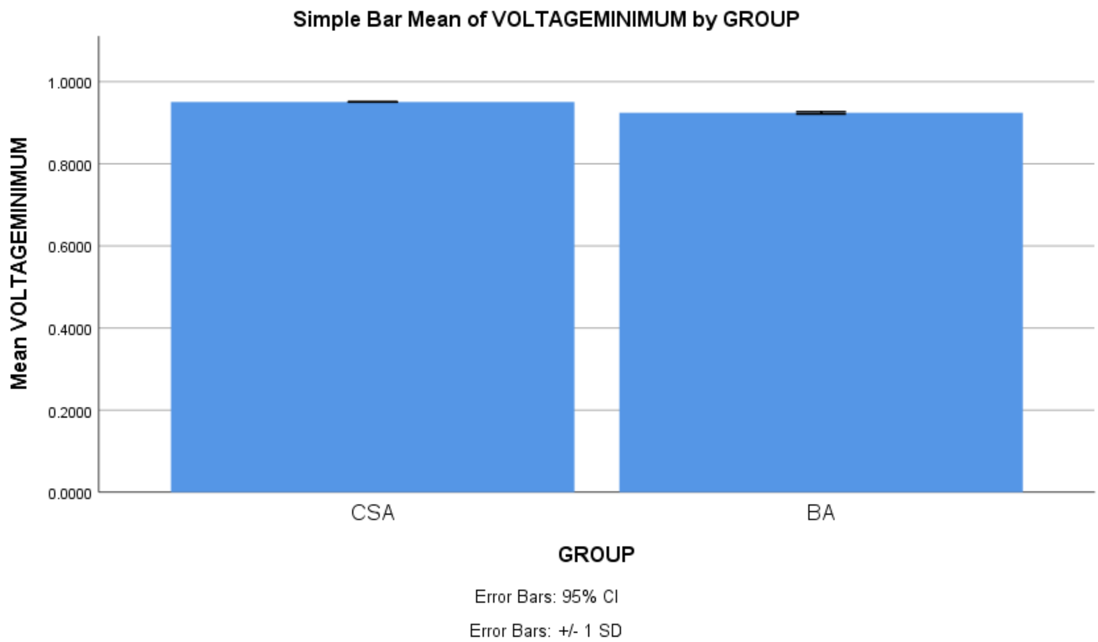


Fig. 5. Comparison of CSA and BA algorithms in terms of mean voltage. CSA (≈0.9507p.u) produces better bus voltage enhancement than BA (≈0.9469p.u). X-axis: CSA vs BA algorithms. Y-axis: mean voltage ± 1 SD.