Voltage Profile Improvement in Radial Distribution System using Plant Growth Simulation Algorithm

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Abstract – A good distribution system should ensure that the voltage variations at consumer’s terminals are within permissible limits. To improve the voltage profile in radial distribution systems, plant growth simulation algorithm (PGSA) has been proposed using optimal capacitor placement. The proposed method is implemented on IEEE 9 bus radial distribution system.

Index Terms - Capacitor placement, capacitor sizing, optimal capacitor allocation, distribution system, voltage profile, voltage improvement, PGSA, Random search algorithm, Bionic search.

I. INTRODUCTION

The main function of a power system is to feed industrial and consumer loads as economically as possible and with a reasonable level of reliability and quality. Distribution system provides the final link between the high voltage transmission system and the consumer. Radial distribution systems are popular because of their simple design and low cost. Radial distribution feeders are typically spread over large urban and rural areas and are becoming large and complex. This stressed the need for an efficient and effective distribution network. The important requirement of a distribution system is that the voltage variations at the consumer’s terminals should be as low as possible. Low and high voltages result in loss of revenue and may cause permanent damage to the equipments. Therefore, a good distribution system should ensure that the voltage variations at consumer’s terminals should be within permissible limits. The statutory limit of voltage is plus minus 5% of rated voltage at the consumer’s terminals [1]. The main cause of voltage drop on the line is the transfer of reactive power (VAr) over the line [2]. Hence, this voltage drop in the line causes more power losses and makes the system uneconomical. Thus, for an economical operation good voltage profile is required and hence, control of reactive power is necessary.

Various optimization techniques and algorithms have been proposed in the past for reactive power compensation to improve the voltage profile such as algorithm based on analytical methods [3-4], numerical programming methods [5-6], heuristics methods [7-8], genetic algorithm [9-11], simulated annealing [12-13], fuzzy logic [14-15], PSO [16-17] and ant colony algorithm [18].

In this paper, voltage profile improvement will be done by Var compensation using optimal capacitor placement with the help of Plant Growth Simulation Algorithm (PGSA). The proposed method is tested on 9 bus radial distribution systems.

II. PROBLEM FORMULATION

The voltage profile can be improved by using optimum size of capacitors at buses. The cost of capacitor placement may increase the cost of system. Hence, the main aim in is to improve the voltage profile in such a way that the total annual cost (TAC) of the system gets minimized. The total annual cost includes the cost equivalent to reduction of power loss in the system, the cost of capacitors and installation cost of capacitor placement. The largest capacitor size cannot be more than total reactive load at a particular bus [19]. Newton Raphson method is used to calculate the voltage of each bus of the system under study. Mathematically, the objective function [20] under certain constraints is given as;
Minimize

Objective function:

\[
\text{TAC} = K_p P_{T, Loss} + \sum_{i=1}^{n} K_i^c Q_i^c + K_f \quad (1)
\]

Subject to

Voltage limit: \( V_{\min,i} \leq V_i \leq V_{\max,i} \) \quad (2)

Capacitor size limit: \( Q_i^c \leq \sum_{i=1}^{n} Q_{Li} \) \quad (3)

Here, \( n \) is the number of buses, \( K_p \) is the equivalent annual cost per unit of power loss in $/kW/year, \( K_i^c \) is the annual capacitor installation cost $/kVAR, \( V_i \) is the voltage magnitude of bus \( i \), \( V_{\min,i} \) and \( V_{\max,i} \) are minimum and maximum voltage limits of \( i^{th} \) bus respectively, \( Q_i^c \) is the reactive power compensated at bus \( i \) and \( Q_{Li} \) is the reactive load power at bus \( i \).

Newton Raphson method is used to calculate the total power loss of the system under study. The three-phase system is considered as balanced and the loads are assumed to be constant.

III. IDENTIFICATION OF OPTIMAL LOCATION

Optimal locations for capacitor placements are the selected buses that can be determined using Loss Sensitivity Factors. The estimation of these buses helps in reduction of the search space for the optimization procedure. A distribution line with an impedance \( R+jX \) and a load of \( P_{eff} + jQ_{eff} \) connected between ‘\( p \)’ and ‘\( q \)’ buses is given below Fig. 1.

![Fig. 1 Distribution Line with p and q Buses](image)

Active power loss in the \( K^{th} \) line is given by \( \left[ j R[k] \right]^{*} R[k] \) which can be expressed as,

\[
\frac{\partial P_{\text{line loss}}}{\partial Q_{eff}} = \frac{2 \cdot Q_{eff} [q] \cdot R[k]}{(V[q])^2 \cdot (V[q])} \quad (5)
\]

Loss Sensitivity Factors \( \frac{\partial P_{\text{line loss}}}{\partial Q_{eff}} \) are calculated from load flow analysis of the given system and the values are arranged in descending order for all the lines of the system. The descending order will decide the sequence in which the buses are to be considered for compensation [22]. Only those buses where the normalized voltage magnitude healthy (i.e. \( V[i] / 0.95 \)) is less than 1.01 are considered as the candidate buses where the capacitor placement needs to be done. If the voltage at a bus in the sequence list is such bus needs no compensation.

IV. PLANT GROWTH SIMULATION ALGORITHM

Plant Growth Simulation Algorithm (PGSA) is a new type of intelligent optimization algorithm which is based on a computer system (namely L-systems) proposed by A. Lindenmayer and P.Prusinkiewicz et al. in the 1990s. L-system is used in the fractal domain and the computer graphics to simulate the plant growing and branching process. When plant outgrows, the main drive to promote its growth impetus comes from the sunlight, the auxin concentrations in plant are changed with photosynthesis, and the point which has received sufficient sunlight with more concentrations will grow prior. By using plant growth simulation algorithm to solve optimization problems is actually a simulation process of plant outgrowing to the whole space. The point which can outgrow a new branch in the plant is called growing point, the more auxin concentration of the growing point, the more growing opportunities it gets. The auxin concentration of plant is mainly decided by phototropic, it will be reassigned among each growing points if the environment location is changed. Tong Li et al. [23] analyzed the probability growth model of simulating the plants phototropic, and gives out auxin concentration calculating formulas of the stems and branches.

Assuming a plant grows a trunk \( M \) from its root and there are \( k \) initial growing points called nodes \( N_{M1}, N_{M2}, N_{M3}, \ldots, N_{Mk} \) that have better environment than the root \( N_0 \) on the trunk \( M \). The auxin concentration \( S_{M1}, S_{M2}, \ldots, S_{Mk} \) of the nodes \( N_{M1}, N_{M2}, \ldots, N_{Mk} \) can be calculated by
The auxin concentration of the growing point can be more if the function of the nodes \( N_{M1}, N_{M2}, N_{M3} \ldots N_{Mk} \) and \( N_0 \) satisfy \( f(N_{Mi}) < f(N_o) \) for \( i=1,2,3 \ldots k \). From (6), it can be calculated that summation of all concentration is equal to unity, which means that the auxin concentrations \( S_{M1}, S_{M2}, \ldots \ldots S_{Mk} \) of the corresponding nodes \( N_{M1}, N_{M2} \ldots N_{Mk} \) form a state space shown in Fig 2.

\[
S_{Mi} = \frac{f(N_0) - f(N_{Mi})}{\sum_{i=1}^{k}[f(N_0) - f(N_{Mi})]} \quad (6)
\]

In the above radial system, there are 9 load buses (from 2 to 10) and one source bus which is indicated by 1. Hence, for this system there are total 10 buses. The voltage of the substation (bus number 1) is assumed to be 1 p.u. For this test feeder, \( K_p \) is selected to be 168$/\text{kW-year}$ [19]. The marginal cost of capacitors (\( K_f \)) [25] are used to compute the total annual cost. The installation cost of capacitor \( K_f \) is taken as $1000. The method of sensitive analysis is used to select the candidate installation locations of the capacitors to reduce the search space. The buses are ordered according to their sensitivity value \( (\frac{\partial P_{\text{losses}}}{\partial Q_{\text{off}}}) \) (i.e., bus 6, 5, 9, 10, 8 and 7). Now, the capacitors are placed on these selected buses using proposed PGSA with all possible combinations of buses. Table I shows the optimal locations of the buses and the corresponding size of capacitors obtained by using proposed PGSA.

![Random Number Generator](image1)

**Fig. 2 Auxin Concentration State Space**

Now randomly generates a number within [0, 1] and drop into one of \( S_{M1}, S_{M2}, \ldots \ldots S_{Mk} \) as shown in Fig 2, the node corresponding to the selected concentration will be the next growing point. Repeat the above process until there is no new branch to grow and hence a complete plant will be formed.

Chung Wang et al. [24] suggested a model where the nodes on a plant can express the possible solutions, \( f(N) \) can express the objective function, the length of the trunk and the branch can express the search domain of possible solutions, the root of a plant can express the initial solution, the preferential growth node corresponds to the basic point of the next searching process. In this way, the growth process of plant phototropism can be applied to solve the problem of integer programming.

## V. APPLICATION OF PROPOSED METHOD

The proposed method has been programmed using MATLAB. The effectiveness of the proposed method for loss reduction by capacitor placement is tested on 9-bus test radial distribution systems [20]. The single line diagram is shown in Fig. 3. The rated line voltage of the system is 23 kV.

![Single Line Diagram of Bus Network](image2)

**Fig. 3 9-Bus Distribution Network**

In the above radial system, there are 9 load buses (from 2 to 10) and one source bus which is indicated by 1. Hence, for this system there are total 10 buses. The voltage of the substation (bus number 1) is assumed to be 1 p.u. For this test feeder, \( K_p \) is selected to be 168$/\text{kW-year}$ [19]. The marginal cost of capacitors (\( K_f \)) [25] are used to compute the total annual cost. The installation cost of capacitor \( K_f \) is taken as $1000. The method of sensitive analysis is used to select the candidate installation locations of the capacitors to reduce the search space. The buses are ordered according to their sensitivity value \( (\frac{\partial P_{\text{losses}}}{\partial Q_{\text{off}}}) \) (i.e., bus 6, 5, 9, 10, 8 and 7). Now, the capacitors are placed on these selected buses using proposed PGSA with all possible combinations of buses. Table I shows the optimal locations of the buses and the corresponding size of capacitors obtained by using proposed PGSA.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Un-compensated</th>
<th>Proposed PGSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total losses (kW)</td>
<td>783.77</td>
<td>686.90</td>
</tr>
<tr>
<td>Annual Cost of the system ($/year)</td>
<td>1,31,674</td>
<td>1,17,240</td>
</tr>
<tr>
<td>Optimal locations and Size in kVAR</td>
<td>---</td>
<td>6, 1200</td>
</tr>
<tr>
<td></td>
<td>5, 1950</td>
<td>9, 450</td>
</tr>
<tr>
<td></td>
<td>10, 3050</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Magnitude of Voltage in p.u</th>
<th>Bus number 1</th>
<th>Bus number 2</th>
<th>Bus number 3</th>
<th>Bus number 4</th>
<th>Bus number 5</th>
<th>Bus number 6</th>
<th>Bus number 7</th>
<th>Bus number 8</th>
<th>Bus number 9</th>
<th>Bus number 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0000</td>
<td>0.9929</td>
<td>0.9874</td>
<td>0.9634</td>
<td>0.9480</td>
<td>0.9172</td>
<td>0.9072</td>
<td>0.8890</td>
<td>0.8587</td>
<td>0.8375</td>
</tr>
</tbody>
</table>
| From the results shown in Table I, it is observed that on placing the optimal size of capacitors using PGSA at the selected buses the magnitude of voltage at all
buses has been improved. The minimum voltage before capacitor placement (uncompensated) is 0.8375 p.u at bus number 10 which has improved to 0.8802 p.u after capacitors placement using PGSA.

The power losses have also reduced using proposed method. It can also been seen that the capacitors used in the above method for the improvement in voltage profile has minimized the system overall cost of the system. Fig. 4 shows the improved voltages on the various buses after compensation and the voltages on those buses before the capacitor placement.

![Fig. 4 Bus Voltages](image)

VI. CONCLUSION

A bionic random search Plant Growth Simulation Algorithm (PGSA) for the voltage improvement in the distribution system has been proposed. The loss sensitivity factors are used to determine the candidate locations of the buses required for compensation. The PGSA method is applied on 9 bus distribution system to estimate the required level of shunt capacitive compensation at the optimal candidate locations to improve the voltage profile of the buses in such a way that the power losses and total annual cost of the system should be minimized. PGSA have many characteristics such as fewer parameters, easily coding and implement, fast calculating speed, no more restrictions or requirements in solving the objective function.

VII. REFERENCES


Power Factor Improvement in Radial Distribution System using Bionic Random Search Algorithm

Abstract: For the efficient utilization of electrical power, power factor of the system must not be low. The good power factor results in reduction of losses and improvement of voltage profile of the system. To improve the power factor in a radial distribution system, bionic random search algorithm has been proposed using optimal capacitor placement. The proposed method is implemented on IEEE 15 bus radial distribution system.

Keywords: Power Factor, Capacitor placement, capacitor sizing, optimal capacitor allocation, distribution system, technical losses, annual cost of the system, voltage profile, voltage improvement, PGSA, Random search algorithm, Bionic search.

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1. Introduction:

The main function of a power system is to feed industrial and consumer loads as economically as possible and with a reasonable level of reliability and quality. Distribution system provides the final link between the high voltage transmission system and the consumer. Radial distribution systems are popular because of their simple design and low cost. Radial distribution feeders are typically spread over large urban and rural areas and are becoming large and complex. This stressed the need for an efficient and effective distribution network. Most of the loads in electrical distribution systems are inductive. Inductive loads require two kinds of power; first is working power P (kW) which is required to perform the actual work of creating heat, light, motion, machine output, and so on and second is reactive power Q (kVAr) which is necessary to sustain the magnetic field. Reactive power doesn’t perform useful “work,” but circulates between the generator and the load. Working power also known as active power and reactive power together make up an apparent power. Apparent power (S) is measured in kilovolt-amperes (kVA). Power factor is the ratio of working power to apparent power. It measures how effectively electrical power is being used. A high power factor shows efficient utilization of electrical power, while a low power factor indicates poor utilization of electrical power. The important requirements of a distribution system include good power factor which results in minimum losses and good voltage profile. Fig. 1 is a representation of a network compensated by a reactive power generation device delivering power Qc. The diagram shows that Qc reduces the overall reactive power demand of the system from Q₂ to Q₁. As indicated in the Fig. 1, the power factor of the system improves by decrease in angle from θ₂ to θ₁ which in turn causes the cosine of the angle to increase.
It is further to be noted that this improvement of power factor is applicable from peak load conditions to all other loading conditions of the network through out the day, week and season. Hence, the reactive power compensation is the effective way to improve the power factor. Various optimization techniques and algorithms have been proposed in the past for reactive power compensation such as algorithm based on analytical methods [1-2], numerical programming methods [3-4], heuristics methods [5-6], genetic algorithm [7-9], simulated annealing [10-11], fuzzy logic [12-13], PSO [14-15] and ant colony algorithm [16]. In this paper, power factor improvement will be done by Var compensation using optimal capacitor placement with the help of Bionic Random Search Algorithm The proposed method is tested on 15 bus radial distribution system.

2. Problem Formulation:

The power factor can be improved by using optimum size of capacitors at selected buses. The cost of capacitor placement may increase the cost of system. Hence, the main aim in is to improve power factor in such a way that the total annual cost (TAC) of the system gets minimized. The total annual cost includes the cost equivalent to reduction of power loss in the system, the cost of capacitors and installation cost of capacitor placement. The largest capacitor size cannot be more than total reactive load at a particular bus [17]. The improvement of power factor by minimizing TAC must results in reduction of technical losses and improvement in voltage profile. Mathematically, the objective function [18] of the problem is to be minimized under certain constraints as,

Minimize

Objective function:

\[
\text{TAC = K_pP_T\text{Loss} + \sum_{i=1}^{n} K^c_iQ^c_i + K_f} \tag{1}
\]

Subject to

Voltage limit: \( V_{\text{min},i} \leq V_i \leq V_{\text{max},i} \) \tag{2}

Capacitor size limit: \( Q_i^c \leq \sum_{i=1}^{n} Q_{i,i} \) \tag{3}
Here, \( n \) is the number of buses, \( K_p \) is the equivalent annual cost per unit of power loss in $/kW/year, \( K_i^c \) is the annual capacitor installation cost $/kVar, \( V_i \) is the voltage magnitude of bus \( i \), \( V_{\text{min},i} \) and \( V_{\text{max},i} \) are minimum and maximum voltage limits of \( i^{th} \) bus respectively, \( Q_i^c \) is the reactive power compensated at bus \( i \) and \( Q_i \) is the reactive load power at bus \( i \).

Newton Raphson method is used to calculate the total power loss and voltage of all buses of the system under study. The three-phase system is considered as balanced and the loads are assumed to be constant.

3. Identification Of Optimal Location:

Optimal locations for capacitor placements are the selected buses that can be determined using Loss Sensitivity Factors. The estimation of these buses helps in reduction of the search space for the optimization procedure. A distribution line with an impedance \( R+jX \) and a load of \( P_{\text{eff}} + jQ_{\text{eff}} \) connected between \( 'p' \) and \( 'q' \) buses is given below Fig. 2.

Active power loss in the \( K^{th} \) line is given by \( \left[I_k^2\right]^* R[k] \) which can be expressed as,

\[
P_{\text{line loss}}[q] = \frac{(P_{\text{eff}}'[q] + Q_{\text{eff}}'[q] R[k])}{(V[q])* (V[q])} \quad (4)
\]

Where, \( P_{\text{eff}}[q] \) & \( Q_{\text{eff}}[q] \) are the total effective active and reactive power respectively supplied beyond the node \( q \).

Now, the Loss Sensitivity Factors [19] can be given by

\[
\frac{\partial P_{\text{line loss}}}{\partial Q} = \frac{(2 * Q_{\text{eff}}[q] R[k])}{(V[q])* (V[q])} \quad (5)
\]

Loss Sensitivity Factors \( (\partial P_{\text{line loss}} / \partial Q_{\text{eff}} ) \) are calculated from load flow analysis of the given system and the values are arranged in descending order for all the lines of the system.
descending order will decide the sequence in which the buses are to be considered for compensation [20]. Only those buses where the normalized voltage magnitude healthy (i.e. \( V[i] / 0.95 \)) is less than 1.01 are considered as the candidate buses where the capacitor placement needs to be done. If the voltage at a bus in the sequence list is such bus needs no compensation.

4. **Plant Growth Simulation Algorithm:**

Random search algorithms are useful for optimization problems with continuous or discrete variables and these algorithms give a guarantee of optimization for finding a best solution with quick convergence. Plant Growth Simulation Algorithm (PGSA) aims at a global optimization of integer programming and it is a kind of bionic random algorithm which occurs in the nature. This algorithm provides an artificial environment which is similar to the environment as provided by the phototropism for the growth of the plant. Plant Growth Simulation Algorithm (PGSA) is a new type of intelligent optimization algorithm which is based on a computer system (namely L-systems) proposed by A. Lindenmayer and P. Prusinkiewicz *et al.* in the 1990s. L-system is used in the fractal domain and the computer graphics to simulate the plant growing and branching process. When plant outgrows, the main drive to promote its growth impetus comes from the sunlight, the auxin concentrations in plant are changed with photosynthesis, and the point which has received sufficient sunlight with more concentrations will grow prior. By using plant growth simulation algorithm to solve optimization problems is actually a simulation process of plant outgrowing to the whole space. The point which can outgrow a new branch in the plant is called growing point, the more auxin concentration of the growing point, the more growing opportunities it gets. The auxin concentration of plant is mainly decided by phototropic, it will be reassigned among each growing points if the environment location is changed. Tong Li *et al.* [21] analyzed the probability growth model of simulating the plants phototropic, and gives out auxin concentration calculating formulas of the stems and branches.

Assuming a plant grows a trunk \( M \) from its root and there are \( k \) initial growing points called nodes \( N_{M1}, N_{M2}, N_{M3}, ..., N_{Mk} \) that have better environment than the root \( N_0 \) on the trunk \( M \).

The auxin concentration \( S_{M1}, S_{M2}, ..., S_{Mk} \) of the nodes \( N_{M1}, N_{M2}, ..., N_{Mk} \) can be calculated by
The auxin concentration of the growing point can be more if the function of the nodes $N_{M1}, N_{M2}, N_{M3}, ..., N_{Mk}$ and $N_0$ satisfy $f(N_{Mi}) < f(N_0)$ for $i=1,2,3,...,k$. From (6), it can be calculated that summation of all concentrations is equal to unity, which means that the auxin concentrations $S_{M1}, S_{M2}, ..., S_{Mk}$ of the corresponding nodes $N_{M1}, N_{M2}, ..., N_{Mk}$ form a state space shown in Fig 3.

\[ S_{Mk} = \frac{f(N_0) - f(N_{Mi})}{\sum_{i=1}^{k} [f(N_0) - f(N_{Mi})]} \]  \hspace{1cm} (6)

Now randomly generates a number within $[0, 1]$ and drop into one of $S_{M1}, S_{M2}, ..., S_{Mk}$ as shown in Fig.2, the node corresponding to the selected concentration will be the next growing point. Repeat the above process until there is no new branch to grow and hence a complete plant will be formed.

Chung Wang et al. [22] suggested a model where the nodes on a plant can express the possible solutions, $f(N)$ can express the objective function, the length of the trunk and the branch can express the search domain of possible solutions, the root of a plant can express the initial solution, the preferential growth node corresponds to the basic point of the next searching process. In this way, the growth process of plant phototropism can be applied to solve the problem of integer programming.

5. Application Of Proposed Method:

The proposed method has been programmed using MATLAB. The effectiveness of the proposed method for loss reduction by capacitor placement is tested on 15-bus test radial distribution systems [23]. The single line diagram is shown in Fig. 4. The rated line voltage of the system is 11 kV.
Total load active and reactive power of this system are 1226 kW and 1251 kVAr respectively. For this test feeder, \( K_P \) is selected to be 168$/(kW-year) [17]. The marginal cost of capacitors \( (K'_c) \) [24] are used to compute the total annual cost. The installation cost of capacitor \( K_f \) is taken as $1000. The method of sensitive analysis is used to select the candidate installation locations of the capacitors to reduce the search space. The buses are arranged in descending order according to their sensitivity value \( (\partial P_{\text{line}}/\partial Q_{\text{loss}}) \) (i.e., bus 6, 3, 11, 4, 12, 15, 14, 7, 13, 8 and 5). Now, the capacitors are placed on these selected buses using proposed PGSA with all possible combinations of buses. Table I shows the optimal locations of the buses and the corresponding size of capacitors obtained by using proposed PGSA.

![Figure 4: 15-Bus Distribution Network](image_url)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Un-compensated</th>
<th>Proposed PGSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal locations and Size in kVAr</td>
<td>---</td>
<td>6 450</td>
</tr>
<tr>
<td></td>
<td>3 150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11 150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 450</td>
<td></td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.70</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td><strong>Total Annual Cost of the system ($ / year)</strong></td>
<td>10,381</td>
<td>6,514.50</td>
</tr>
<tr>
<td><strong>Total losses (kW)</strong></td>
<td>61.8</td>
<td>30.6</td>
</tr>
<tr>
<td><strong>Magnitude of Voltage in p.u at bus number 13</strong></td>
<td>0.9445</td>
<td>0.9709</td>
</tr>
</tbody>
</table>

*Table I*

*Simulation Results of 15- Bus System and Its Comparison*

From the Table I, it can be concluded that power factor has been improved from 0.70 to 0.99 by placing optimal size of capacitors at candidate buses using proposed PGSA. It can also be observed that the improvement of power factor results in minimization of total annual cost (TAC) of the system, reduction of losses and improvement of voltage at bus number 13. Improvement in the power factor has also improved the voltage profile of all the buses (except bus number 1 which is a slack bus) as shown in Fig. 5.
6. **Conclusion:**

PGSA which is a bionic random search algorithm has been proposed for power factor improvement in the distribution system. The loss sensitivity factors are used to determine the candidate locations of the buses required for compensation. The PGSA method is applied on 15 bus distribution system to estimate the required level of shunt capacitive compensation at the optimal candidate locations to improve the power factor in such a way that total annual cost of the system and the power losses should be minimized. PGSA have many characteristics such as fewer parameters, easily coding and implement, fast calculating speed, no more restrictions or requirements in solving the objective function.

![Figure 5: Bus Voltages](image-url)
References:


