A hybrid MACO and BFOA algorithm for power loss minimization and total cost reduction in distribution systems

Muthubalaji SANKARAMOORTHY\(^1\), Malathi VELUCHAMY\(^2\)
\(^1\)Department of Electrical and Electronics Engineering, Lathamathavan Engineering College, Alagarkoil, Madurai, Tamil Nadu, India
\(^2\)Department of Electrical and Electronics Engineering, Anna University Regional Campus, Madurai, Tamil Nadu, India

Abstract: This paper presents a multiobjective optimization methodology to optimally place a STATCOM in electric power distribution networks. The combination of multiobjective ant colony optimization (MACO) and the bacterial foraging optimization algorithm (BFOA) is proposed to minimize the power loss and total cost. The main intention of this analysis is to optimally place the STATCOM at multiple locations such as the transmission side, middle, and load side. Identifying the type and location of the STATCOM is a combinatorial optimization problem in power systems. In order to overcome this problem, the combination of hybrid MACO and BFOA algorithms is applied in this analysis to minimize the total cost and power loss. The total cost of the overall network is calculated by using system average interruption duration index and system average interruption frequency index metrics. Moreover, the BFOA is used in this paper to minimize the power loss during distribution, which is adequate in searching for the optimal solution.

Key words: Multi-objective ant colony optimization, bacterial foraging optimization algorithm, system average interruption duration index, system average interruption frequency index, STATCOM, electric power distribution, system reliability

1. Introduction

Electric power distribution is the process of distributing electrical power to end users. The electrical power produced at the generating station is transferred to the end users through a distribution system and a network of transmission systems. Generally, the distribution system [1] is one part of a power system, which distributes the power to end users for utilization. All distribution of electrical energy and power is done by using a constant voltage system. A static synchronous compensator (STATCOM) is a type of flexible alternating current transmission system (FACTS) [2] device, which is mainly used for voltage stability maintenance and reactive power compensation in power systems. In this paper, the STATCOM [3] is mainly used for reactive power compensation and voltage stability enhancement. It contains an insulated gate bipolar transistor (IGBT)-based voltage converter for reactive power compensation and voltage control in power systems. It is also used to enhance the transient stability and control the power flow. It is a voltage source and a converter-based
device, which converts a DC input voltage into an AC output voltage in order to compensate the active and reactive needs of the system. The STATCOM regulates the voltage by controlling the amount of reactive power in the power system. It provides many advantages, specifically a fast response time and higher voltage support capability with the nature of its voltage source. Here the single STATCOM device is placed in multiple locations, so the optimal location of the STATCOM is concentrated on in this analysis in order to compensate the reactive power based on MATLAB/Simulink.

In this analysis, a combined hybrid approach, namely multiobjective ant colony optimization (MACO) with the bacterial foraging optimization algorithm (BFOA), is proposed with the objectives of power loss and total cost minimization. The MACO [4] algorithm is suggested to solve multiobjective optimization problems. The main intention of using MACO is to minimize the total cost of the power distribution systems. The basic idea of ant colony optimization (ACO) is to choose the minimum cost path and to use artificial ants for searching for good paths. It is a metaheuristic approach effectively applied to single-objective combinatorial optimization problems. In this work, MACO [5] is developed to solve multiobjective optimization problems. The single-objective optimization problem is trying to find the single solution, namely the optimal solution. It minimizes or maximizes a particular objective function to a given constraint. Instead, multiobjective optimization problems consider disparate objectives that have to be simultaneously optimized.

The system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) [6] are used to identify the optimal location of a STATCOM device. The main objectives of SAIDI are to estimate the power and find the error location in the distribution system. The work of SAIFI is to identify the best place for power loss minimization and calculate the best fitness value. The output information of MACO is given to the input of BFOA. It is a novel evolutionary computation algorithm based on the foraging behavior of Escherichia coli bacteria. In the classical BFOA, an individual bacterium attempts to get a sufficient amount of nutrient substance and avoid harmful substrates. The individual bacterium tries to optimize these two problems simultaneously and it is also applied to multiobjective optimization. Additionally, the BFOA is proposed in this paper to minimize the power loss in distribution systems. The BFOA [7] has been broadly accepted as a global optimization algorithm for distributed optimization and control.

The remaining part of the paper is organized as follows: Section 2 involves the works related to probable solutions for power loss and total cost minimization. Section 3 involves the description of the proposed method for optimal STATCOM placement by using MACO and the BFOA. Section 4 involves the performance analysis of the proposed work. The paper is concluded in Section 5.

2. Related work
This section presents the existing techniques and algorithms related to optimal placement of a STATCOM, power loss minimization, and total cost reduction in electric power distribution systems. Goel et al. [8] suggested a genetically tuned STATCOM device for voltage stability and reactive power compensation in power distribution systems. The authors developed a STATCOM device to demonstrate its effectiveness during the maintenance of voltage regulation. In this analysis, the values of the DC link capacitor and battery source were optimized using the genetic algorithm (GA). Mohanty and Barik [9] suggested a FACTS device to improve the power system stability in electric power distribution system. FACTS controllers were mainly used for solving various power system steady-state control problems. The advantages of using FACTS controllers are that they increase the reliability and availability of power transmission systems. They also increased the dynamic and transient grid availability and reliability. Rohit et al. [10] surveyed the applications of STATCOMs for power quality
enhancement. A STATCOM was mainly used to reduce the transmission congestions and other power system problems. Goswami et al. [11] recommended FACTS devices to minimize the voltage sag in distribution systems. FACTS devices were originally refined for transmission networks, but similar ideas were applied in distribution systems.

Alaya et al. [12] presented a GA-based ACO approach to solve multiobjective optimization problems. In this study, the suggested algorithm was parameterized by the number of ant colonies and the number of pheromone trails. Moncayo et al. [13] recommended a unique approach to determine the supply chain design for complex hierarchies of subassemblies and components. This paper presented a Pareto ACO algorithm for solving multiobjective problems, which was an effective metaheuristic method in power distribution systems. Mohamed and Kowsalya [14] proposed an effective method, the fireworks algorithm, for solving the network configuration problem. The main intention of this paper was to minimize the power loss and improve the voltage stability in power distribution systems. In this study, the radial structure of the network was monitored by generating proper parent node-child node paths of the system. Zhao et al. [15] developed an ACO and differential evolution algorithm for reactive power optimization in distribution systems. The main intention of this paper was to minimize the power loss and solve an actual reactive optimization problem in power distribution systems. Akorede et al. [16] presented a review of various methodologies for optimal placement of distributed generation (DG) in power distribution systems. In this analysis, the ACO algorithm was used to solve the optimization problem under consideration.

Sathish Kumar and Jayabarathi [17] designed a BFOA for power distribution networks. The main intention of this paper was to find the optimal solution and minimize the power loss in distribution systems. In this paper, a fast and effective approach was proposed, which was highly suitable for distribution automation systems. Kumar and Jayabarathi [18] proposed a reconfiguration method to minimize the power loss and load-balancing index in power distribution systems. The BFOA was used in this study to formulate the feeder configuration problem and to find the optimal solution. In this paper, the radial structure of the power distribution system was retained and the burden of the optimization technique was also reduced. Abd-Elazim et al. [19] suggested a BFOA-based power system stabilizer (PSS) for the suppression of oscillations in a power system. In this paper, the BFOA was employed to minimize the processing time by searching for optimal controller parameters. The PSS was robustly designed in this study to stabilize the multimachine power system oscillations.

Vivekananthan et al. [20] presented an effective method to improve voltage stability and reduce the power loss by using the BFOA approach. In this paper, three types of FACTS devices, namely a static VAR compensator, thyristor-controlled series capacitor, and unified power flow compensator, were selected to improve the voltage stability margin in electric power systems. Tehzeeb et al. [21] suggested a fully informed particle swarm optimization (PSO) algorithm to minimize the power loss in power transmission systems. The test cases used in this paper were the Ward-Hale-6-Bus system, the standard IEEE 30-system, and the standard IEEE 118-bus system. Naik et al. [22] presented an analytical approach for optimal allocation and real power loss minimization in distribution networks. A sensitivity analysis technique was utilized to identify the optimal candidate locations for DG and capacitor placement. Bamigbola et al. [23] proposed a mathematical model for minimizing power losses on transmission lines. The main objective of this paper was to address a well-known engineering problem, reducing the power losses to the barest minimum.

Kayal and Chanda [24] suggested a new-constraint multiobjective PSO algorithm for power loss reduction and voltage stability enhancement in radial distribution system. The authors recommended a voltage stability
factor that was used to quantify the voltage stability levels in the system. The suggested factor was a more simple and efficient tool when compared with the other voltage stability index and power stability index. Di Fazio et al. introduced an online optimization strategy to minimize the power losses along the feeder in power control systems [25]. Numerical results were presented in this analysis to give evidence of power loss reduction in power control systems. Duan et al. [26] proposed an enhanced GA for power loss reduction and reliability enhancement in distribution networks. This was used to handle both the reconfiguration problem and switch operations. The effectiveness of this method was illustrated in 33-bus, 69-bus, and 136-bus radial distribution systems. Moradi and Abedini [27] suggested a combination of the GA and PSO for optimal location and sizing of DG in distribution power systems. The main objective of this paper was to minimize the power losses and improve the voltage stability in power systems.

The existing methods have some drawbacks, such as power loss and cost effectiveness. In order to overcome these limitations, MACO with the BFOA is proposed in this paper. When compared with the existing methods, the proposed method can efficiently attain power loss minimization, total cost reduction, and better system reliability.

3. MACO with BFOA

In this paper, a combination of MACO and BFOA is proposed to minimize both the power loss and total cost. Moreover, optimal placement of a STATCOM is concentrated on to maintain system reliability and power loss minimization. Here, the MACO algorithm is used to reduce the total cost and the BFOA approach is used to minimize the power loss during the electrical power distribution to the end users. The proposed approach performs well and provides the best results when compared with the existing optimization algorithms.

3.1. Optimal placement of the STATCOM

A STATCOM is a type of FACTS device, which provides the reactive support to a bus. It contains voltage-sourced converters that are connected to an energy storage device on one side and to the power system on the other. In the STATCOM, static is the first component, which is based on a solid-state switching device with no rotating components. The second component is synchronous that is analogous to an ideal synchronous machine with three sinusoidal phase voltages. The third component is a compensator that provides the reactive power compensation. A STATCOM is a shunt-connected FACTS device, which is mainly used to reduce the real power loss by adjusting the reactance. Buses with high angle sensitivity are chosen as the location of STATCOM placement, because it is more prone to rotor angle instability.

The Simulink model for STATCOM placement is shown in Figure 1. In this analysis, the main objective of using the STATCOM is to minimize the power loss and increase the voltage profile. The primary objective of optimal placement of a STATCOM in power distribution systems is to distribute the electrical power to the end users. Thus, it minimizes the power loss during power distribution. This paper discusses the comparative analysis before and after optimal placement of the STATCOM in power distribution systems. The specific design of the STATCOM provides reactive power minimization along with an increased voltage profile. In this paper, a single STATCOM is placed in multiple locations such as the transmission side, middle path, and load side. It efficiently improves the system reliability and minimizes the power loss.
3.2. Multiobjective ant colony optimization (MACO)

This paper presents a MACO algorithm for achieving the best system reliability while simultaneously minimizing the total cost of the system. In a single-objective ACO, the components of high-quality solutions receive more pheromones. In MACO, the objective function is multidimensional and not scalar, and there is only a partial order among the solutions. In this paper, multiobjective optimization was considered to find the optimal location of the STATCOM. The optimality of multiobjective problems is based on Pareto optimal sets. It is used to evaluate the relation between two candidate solutions. The Pareto optimality principle forms a partial order among multiple solutions without any a priori preference information. The output of this algorithm becomes a set of nondominated solutions rather than a single one. MACO algorithms exhibit various design choices for dealing with the particularities of multiobjective content.

Figure 2 illustrates the overall flow of the proposed framework. Initially, the power distribution network is formed by using 5-bus systems to optimally place the STATCOM. After that, the best compromise solution is selected from the Pareto set by using Pareto optimality. The diversity among the Pareto-optimal solutions is maintained by using the combination of hybrid MACO and BFOA. Hence, the total cost is calculated for the overall network by using SAIDI and SAIFI. Finally, the minimized total cost and power loss are obtained by using the MACO with BFOA.

3.3. System average interruption frequency index (SAIFI)

There are many reliability indices used to evaluate the cost function of power distribution systems. In this paper, the most commonly used methods, SAIDI and SAIFI, are used to measure the impact of power outages. SAIFI is the system average interruption frequency index, which is mainly used to present the average frequency of sustained interruptions per customer.
Here, $\lambda_{is}$ represents the permanent failure rate of load point $i$ due to ages in section $e$. $\lambda_{is}$ can be determined by using the following equation.

$$
\lambda_{is} = \begin{cases} 
\lambda_s & \text{if } S_e \cap (R \cup F) - L_i \cap (R \cup F) = \emptyset \\
0 & \text{Otherwise}
\end{cases}
$$

Here, $\lambda_s$ represents the permanent failure rate of section $e$. $A_i$ is the number of customers at load point $i$, $k$, and $r$, which describe the number of load points and sections, respectively.

3.4. System average interruption duration index (SAIDI)

SAIDI is the system average interruption duration index, which is usually referred to as customer minutes of interruptions. It is established to calculate the average time that a customer is interrupted during a year.
Here, $c_{is}$ defines the average outage time per interruption of load point $i$ due to outages in section $e$. $\lambda_{is}$ represents the permanent failure rate as defined in Eq. (2). $c_{is}$ depends on the circuit topology and location of switches, which is determined by using the following equation.

$$c_{is} = \begin{cases} c_{cs} & \text{if } S_e \cap D - L_i \cap D = \emptyset \\ c_w & \text{or } S'_e \cap D - L'_i \cap D = \emptyset \\ c_{ws} & \text{Otherwise} \end{cases}$$

Here, $S'_e$ and $L'_i$ are complements of $S_e$ and $L_i$ respectively. $c_{cs}$ and $c_{ws}$ represent the repair time and switching time.

### 3.5. Total cost minimization

The main objective function of the total cost minimization is the sum of the fixed cost associated with capital investment on switches and protective devices and the cost of interruptions. Eq. (5) shows the total cost calculation.

$$\text{Total cost} = FC + \sum_{i=1}^{k} \sum_{e=1}^{r} (CP_{is} + CT_{is})$$

Here, $FC$ is the fixed cost, which includes the installation cost of switches and protective devices. The interruption costs for each load point $i$ due to outages in section $e$ consist of interruption costs due to both permanent and temporary faults. $CP$ represents the cost of interruptions due to the permanent faults and $CT$ represents the cost of interruptions due to the temporary faults, which are defined in the following equations.

$$CP = I_{is} (c_{is}) AL_i \lambda_{is}$$

$$CT = I_i AL_i \gamma_{is}$$

Here, $AL_i$ defines the average load at load point $i$. $\gamma_{is}$ represents the temporary failure rate at load point $I$ due to outages in section $e$, as illustrated by the following equation.

$$\gamma_{is} = \begin{cases} \gamma_e & \text{if } S_e \cap R - L_i \cap R = \emptyset \\ 0 & \text{Otherwise} \end{cases}$$

Here, $\gamma_e$ represents the temporary failure rate of section $e$. $I_i$ defines the cost per kilowatt of temporary outages. $I_{is}(c_{is})$ is the permanent interruption cost per kilowatt of load point $I$ due to outage in section $e$ with duration of $c_{is}$.
3.6. Bacterial foraging optimization algorithm (BFOA)

The BFOA is recommended in this paper for electrical power distribution networks with the objective of loss minimization. According to the aspects of the distribution network, some alterations are done to retain the radical structure and reduce the searching requirement. The problem of reducing power losses in electrical systems using the BFOA approach is discussed here for a 5-bus distribution network. In this paper, the BFOA is implemented to optimally place the STATCOM in order to minimize the power loss in distribution systems. The BFOA is an optimization method based on the population search, which is efficient for the global search method. The power loss minimization problem in a distributed system is to find the best configuration of a network, which gives the minimum power loss while the imposed operating constraints are satisfied. Mathematically, the objective function of the problem is minimizing the loss and cost in distribution networks. This function is:

\[ F = O_1 \times P_{\text{loss}} + O_2 \times \sum_{i=1}^{n} (1 - m_i)^2, \]  

(9)

where \( O_1 \) and \( O_2 \) are objective function coefficient for power loss and objective function coefficient for voltage deviation. \( P_{\text{loss}} \) is the total loss in the transmission system and \( m_i \) represents the voltage magnitude of the \( i \)th load. The complex power at the \( i \)th bus is given by the following relation:

\[ A_i - jR_i = V_i \times I_i, \]  

(10)

where \( A_i \) represents the load active power, \( R_i \) represents the load reactive power, \( V_i \) describes the voltage at the \( i \)th bus, and \( I_i \) defines the load current at the \( i \)th bus. The 5-bus voltage and line losses are calculated by using the BFOA method, which is shown in Eq. (11).

\[
V_i^{(k+1)} = \frac{1}{a_{ii}} \left( \frac{A_i - jR_i}{V_i^{(k)}} \right) - \sum_{n \neq i}^{m} a_{in}V_n
\]

(11)

Here, \( V_i^{(k)} \) represents the voltage of bus \( i \) at the \( k \)th iteration. \( A_i \) and \( R_i \) define the active and reactive power of bus \( i \). The power losses in the line section between buses \( i \) and \( i+1 \) are calculated by:

\[
P_{\text{loss}}(i, i+1) = E_{i, i+1} \left| |V_{i+1} - V_i| \cdot |a_{i, i+1}| \right|^2,
\]

(12)

\[
a_{i, i+1} = \frac{1}{(E_{i, i+1} + F_{i, i+1})},
\]

(13)

where \( a_{i, i+1} \) represents the line section between buses \( i \) and \( i+1 \). \( E_{i, i+1} \) and \( F_{i, i+1} \) define the resistance and reactance of the line connection in buses \( i \) and \( i+1 \). The total power loss is given by the following relation.

\[
P_{\text{loss}} = \sum_{i=0}^{mn} P_{\text{loss}}(i, i+1)
\]

(14)

4. Performance analysis

This section presents the experimental results and analysis of the proposed hybrid MACO with BFOA algorithm. In this paper, a MATLAB simulation applies MACO with the BFOA method for optimal placement of the STATCOM. The simulation results of this system provide significant insight into the useful characteristics.
Algorithm 1 MACO and BFOA

Input: Problem occurring source
\[ G(x) = (g_1(x) \ldots g_n(x)) = n \text{ objective functions} \]
\( \alpha_s \rightarrow \text{Rate of section} \)
\( Q_s \rightarrow \text{Interruption cost} \)
\( R \rightarrow \text{Permanent interruption} \)
\( \lambda \rightarrow \text{Rate of load point} \)
\( FC \rightarrow \text{Fixed cost} \)
\( pis \rightarrow \text{Depends on circuit topology} \)
\( TC \rightarrow \text{Total cost} \)
\( \beta_a, \beta_b, \beta_c \rightarrow \text{are visibilities of object function} \)

Power loss calculation by BFOA

Output: Best solution

Begin

Step 1: To load input source (i.e. programmable voltage source)
Step 2: To find Pareto optimal set
\[ \min G(x) = (g_1(x) \ldots g_n(x))^T \]
Where \( g_1(x) \ldots g_n(x) \) represents the \( n \) objective functions.
Step 3: To solve objective function problem by MACO
\[ \mu_s = \begin{cases} 
\alpha_s & \text{if } Q_s \leq (R \cap S) + (R \cap S) \\
0 & \text{otherwise} 
\end{cases} \]
Where \( \mu_s \) defines the objective function, \( \alpha_s \) is the rate of section, \( Q_s \) is interruption cost, \( R \) is permanent interruption.
Step 4: Power optimization \( E = M \cdot Q \cdot \beta \cdot f \)
Where \( M \) defines the magnitude, \( Q \) represents the reactive power, and \( f \) represents the fitness value.
Step 5: Find SAIFI, SAIDI, and total cost
\[ \text{SAIFI} = \sum_{i=1}^{k} \left( \frac{\sum_{i=1}^{\lambda s i} A_i}{\sum_{i=1}^{\lambda s i}} \right) \]
\[ \text{SAIDI} = \sum_{i=1}^{k} \left( \frac{\sum_{i=1}^{\lambda s i c i} A_i}{\sum_{i=1}^{\lambda s i}} \right) \]
\[ \text{TC} = FC + \sum_{i=1}^{k} \sum_{i=1}^{\lambda s i} (SAIDI + SAIFI) \]
Step 6: Get best system reliability
\[ \beta_a = \frac{1}{(SAIFI)} \]
\[ \beta_b = \frac{1}{(SAIDI)} \]
\[ \beta_c = \frac{1}{(TC)} \]
Where \( \beta_a, \beta_b, \beta_c \) are visibilities of objective function.
Step 7: Power loss calculation using BFOA
\[ \eta^j (k + 1, u, q) = \eta^j (k, u, q) + B(i)\phi(k) \]
\[ \text{Pc} (\phi) = \left[ \sum_{k=1}^{L_{exp}} \left( -\delta \sum_{l=1}^{(\phi 1 + \phi 2)^2} \right) - \left[ \sum_{k=1}^{M_{exp}} \delta \sum_{i=1}^{(\phi 1 + \phi 2)^2} \right] \right] \]
Step 8: Find optimized solution

End
4.1. Output waveform

Figure 3 illustrates the output waveform result for current, voltage, and power. In this graph, the x-coordinates represent the time in seconds and the y-coordinates represent the values of output current, power in watts and amplitude in volts. In the current graph, the pink waveform denotes the reference current \( I_{qref} \) in terms of per unit and the yellow waveform denotes the output current \( I_q \). In the power graph, the pink waveform represents the real power \( P \) and the yellow waveform represents the reactive power \( Q \). In the voltage graph, the yellow waveform defines the output voltage \( V_{dc} \). The real power is the portion of the power flow average over a complete cycle of the AC waveform that results in a net transfer of energy in one direction. The reactive power is the portion of power flow due to stored energy that returns to the source cycle in each cycle.

4.2. STATCOM current

Figure 4 depicts the output waveform of STATCOM current, power in watts and amplitude in volts. In this graph, the x-coordinates denote the time in seconds and the y-coordinates denote the power in watts, amplitude in volts, and current. In the PQ B3 graph, the yellow waveform illustrates the real power and the pink waveform illustrates the reactive power. In the V B1, V B2 graph, the yellow waves denote the bus 1 voltage and the pink waves denote the bus 2 voltage. In the \( I_a \) STATCOM graph, the yellow waveform represents the output current of the STATCOM.

![Figure 3. Output waveform.](image)

![Figure 4. Output STATCOM current.](image)

4.3. Optimized cost value

Figure 5 illustrates the total cost optimization graph using MACO. In this research, the MACO algorithm has been applied to the problem of total cost minimization, while simultaneously minimizing the two indices, SAIDI and SAIFI. This algorithm is used to find the optimal number and locations of STATCOMs to minimize the
total cost for the entire power network. Figure 6 illustrates the cost values for best, mean, and worst cases. From this graph, it is observed that the proposed method obtains the minimum cost value.

Figure 5. Total cost optimization using MACO.

Figure 6. Cost values for best, mean, and worst cases.

4.4. Before and after optimization

In this analysis, the 5-bus system is used for power loss minimization and total cost optimization. Here, P and Q represent the real and reactive powers. MVar defines a megaunit of reactive power in power systems and its basic unit is volt amperes reactive (VAR). In an AC circuit, the impedance is pure resistance and the voltage and current are in phase, which is shown in Eq. (15).

\[ P = E_{rms}I_{rms} \]  

(15)

Here, P defines the power in watts, Erms defines the root mean square (rms) voltage in volts, and lrms is the current in amperes. Table 1 shows the optimization results before and after using the hybrid MACO and BFOA algorithm. In this analysis, the IEEE 5-bus system is used to evaluate the performance of the proposed system. The voltage magnitude represents the voltage values in terms of per unit (pu) at each bus system. The angle degree represents the phasor differences for each and every bus line. Before optimization, the required load power (real and reactive) is minimum and the generator’s real and reactive power needs to generate high power. Based on these values, the loss of power is calculated at the load side. The power loss is high before optimization, so in order to reduce the loss, optimization is performed. After optimization, both the load power and generator power are increased and this reduces both the power loss and total cost.

4.5. Optimized output results

From this analysis, it is observed that the total loss is minimized to 1.7533 MW, which is shown in Table 2. The power loss occurs during the distribution of input signals, which is minimized using the BFOA. Here, the power loss, voltage profile (VP), load balance (LB), and DSTATCOM power are analyzed for various generator powers such as 20 MW, 25 MW, 30 MW, 35 MW, and 40 MW. The graphical representations for this analysis are shown in Figures 7–10. Here, the generator power for the overall buses is provided, and for each variation, the generated power losses are illustrated. The VP is defined as the difference between the reference voltage
and actual bus voltage and it should be minimum. The LB is defined as the required bus current and the DSTATCOM power is the required power for placing the bus in the power system. From these optimization results, it is seen that the power loss of the overall system is reduced.

Table 1. Before and after optimization results.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.060</td>
<td>0.253</td>
<td>0.000</td>
<td>26.930</td>
<td>670.90</td>
<td>2223.22</td>
<td>0.418</td>
<td>2.379</td>
<td>29.309</td>
<td>159.58</td>
<td>528.86</td>
<td>0.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.043</td>
<td>22.273</td>
<td>21.700</td>
<td>0.000</td>
<td>40.000</td>
<td>5567.73</td>
<td>0.765</td>
<td>24.091</td>
<td>2.391</td>
<td>9.565</td>
<td>1331.44</td>
<td>0.322</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.012</td>
<td>21.900</td>
<td>2.400</td>
<td>0.000</td>
<td>42.000</td>
<td>0.000</td>
<td>0.930</td>
<td>4.790</td>
<td>2.390</td>
<td>0</td>
<td>0</td>
<td>0.483</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3.267</td>
<td>24.166</td>
<td>7.600</td>
<td>0.000</td>
<td>24.000</td>
<td>0.000</td>
<td>0.805</td>
<td>9.977</td>
<td>2.377</td>
<td>0</td>
<td>0</td>
<td>0.363</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.010</td>
<td>49.457</td>
<td>94.200</td>
<td>0.000</td>
<td>132.000</td>
<td>-43.064</td>
<td>0.800</td>
<td>96.593</td>
<td>2.393</td>
<td>0</td>
<td>10.30</td>
<td>0.357</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Results of hybrid MACO and BFOA algorithm.

<table>
<thead>
<tr>
<th>Generator power (MW)</th>
<th>P Loss (MW)</th>
<th>VP</th>
<th>LB (%)</th>
<th>DSTATCOM (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 MW</td>
<td>1.2199</td>
<td>0.65</td>
<td>96.3</td>
<td>0.87</td>
</tr>
<tr>
<td>25 MW</td>
<td>1.4766</td>
<td>0.72</td>
<td>94.7</td>
<td>1.02</td>
</tr>
<tr>
<td>30 MW</td>
<td>1.2667</td>
<td>0.67</td>
<td>95.1</td>
<td>0.94</td>
</tr>
<tr>
<td>35 MW</td>
<td>1.41</td>
<td>0.66</td>
<td>95.5</td>
<td>1.12</td>
</tr>
<tr>
<td>40 MW</td>
<td>1.7533</td>
<td>0.71</td>
<td>96.9</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Figure 7. Power loss of the proposed BFOA approach. Figure 8. Voltage profile in terms of per unit.

4.6. Optimized fitness value

Figure 11 illustrates the analysis of reactive power loss optimization using the BFOA. The problem of reducing power loss in distribution systems via STATCOM placement through the BFOA approach is analyzed and discussed here for a 5-bus system. For each bus, the parameters are taken, and based on these parameters, the fitness value is calculated. For each instance of iteration, the power loss calculated is defined as the variation of the line. At an iteration at which the load power is generated on a regulated level, the iteration will be stopped. If the iteration is increased, simultaneously, the power loss will be reduced.
5. Conclusion and future work

This paper presents a multiobjective technique for optimal placement of a STATCOM in electric power distribution systems. The power loss and total cost are considered as the objective functions to be simultaneously minimized in order to optimally place the STATCOM. In this paper, a selective procedure is proposed to determine the locations of the STATCOM in a distribution system. The combination of the hybrid MACO and BFOA is proposed in this analysis to minimize the total cost and power loss for the overall network. The total cost is estimated by calculating the SAIDI and SAIFI. The statistic type and location of the STATCOM are identified to simultaneously reduce the SAIFI, SAIDI, and total cost. The BFOA is simple and easy to implement to reduce the power loss in power distribution systems. A BFOA approach is proposed in this paper to keep the load balancing in power systems, so that the loss of power is reduced. Test results have shown that the combination hybrid MACO with BFOA approach can efficiently solve the power loss and total cost minimization problems.
In the future, FACTS devices with DG will be optimized by using an efficient controller in order to reduce the total cost and load regulation in power systems.

References


