Economic Load Dispatch of IEEE-26 Bus System with the use of Ant Colony Optimization Technique

Pirmahamad Jamalbhai Vasovala\textsuperscript{1} Chinmay Y. Jani\textsuperscript{2} Vasim H. Ghanchi\textsuperscript{3} Parth Harshad Kumar Bhavsar\textsuperscript{4}
\textsuperscript{1,2,3}Electrical Engineering Department
\textsuperscript{1,2,3}The Maharaja Sayajirao University of Baroda, Vadodara
\textsuperscript{4}Parul Institute of Engg & Technology, Vadodara

Abstract--- Optimal System operation involves the Consideration of economy of operation, system security, emission of certain fossil-fuel plant. The main aim of this study is to minimize the fuel cost and to keep the power outputs of the generator within prescribed limit with the use of Ant Colony Optimization Techniques. It is based on the ideas of ant foraging by pheromone communication to make path. Ant Colony Optimization technique is a meta-heuristic approach for solving hard combinatorial optimization problems which can be applied for power system optimization. The work reported in this paper is carried out with the objective to make use of Ant colony Optimization for solving the economic load dispatch problem. IEEE-26 Bus 6 generator system is considered to test the Algorithm with cost functions. The proposed approach result has been compared to those which reported in the literature.

Keywords: Ant Colony Optimization, Optimal power flow, meta-heuristic, IEEE Systems, power systems, optimization.

I. INTRODUCTION

Electric power grids are considered to be one of the most complex man-made systems mainly due to their wide geographical coverage, various transactions among different utilities, and diversity in individual electric power companies’ layouts, size, and equipment used. Engineers need special tools to optimally analyze, monitor, and control different aspects of such sophisticated systems. Some of these tools are economic dispatch, unit commitment, state estimation, automatic generation control, and optimal power flow. The main objective of electrical power utility is to ensure that electrical energy requirement from the consumer is delivered. However for doing so, the power utility has also to confirm that the electrical power is generated with reduced cost. So for economic operation of the system, the total demand must be equally shared among the generating units with an objective to minimize the total generation cost for the system. Economic Dispatch is a method to find the electrical power to be generated by the committed generating units in a power system so that the total generation cost of the system is minimized, with satisfying the load demand simultaneously. To show this problem, optimization is a necessary in solving the cost minimization problems. Power system optimization is an important area in the operation, planning and control of power systems. Many advanced heuristic techniques to the solution of complex power system optimization problems have been proposed, each differing in their procedure of representation, implementation and solution procedure:

Economic load dispatch is one of the basic problems in power system operation and planning. It is defined as the process of giving generation levels to the generating units so that the system load is supplied fully and most economically.

It concerned on the reduction of an objective function, usually the total cost of generation, while considering both the equality and inequality constraints. Load variation depends upon the output of generators has to be changed to meet the balance between loads and generation power to make the system efficient. There are a lot of conventional optimization techniques which are applied in solving the ELD problems that are briefly listed in literature reference [8] such as Newton-based techniques, Linear Programming, Non-Linear Programming, Quadratic Programming, Interior point methods, Parametric method, Sequential and unconstrained minimization techniques. However, these methods usually suffer from some disadvantages such as convergence to local solutions instead of global ones if the initial guess is in the vicinity of a local solution, applicability to a specific ELD problem based on its mathematical nature and some inherent theoretical assumptions (such as convexity, differentiability, and continuity) which are inconsistent with the actual OPF formulations [8].

Several stochastic search techniques are also listed and discussed briefly by the researchers of [8] such as genetic algorithms (GA), evolutionary programming (EP), particle swarm optimization (PSO), bacteria foraging (BF) algorithm [8] Ant colony optimization (ACO)[9] have been proposed to solve the OPF problem without any restriction on the shape of the cost curves. The results reported were promising and encouraging for further research in this direction.

The remaining parts of the paper are organized as follows. In the second section, the formulation of ELD problem is briefly introduced. The ant colony optimization algorithm described in section three. The proposed ACO and its application for the solution of the ELD problem are presented in section four. Obtained numerical results from extensive testing of the proposed solution approach on different case studies are presented in section five and compared with the results of several other recently published methods. Section six concludes the paper.
II. ECONOMIC DISPATCH PROBLEM FORMULATION

Economic Dispatch problem can be solved by minimizing the cost of generation in the system. The solution gives the optimal generation output of the online generating units that satisfy the system’s power balance equation under various system and operational constraints. The Economic Dispatch problem can be formulated mathematically as follows

A. Objective Function is to minimize the cost

\[ F = \sum_{i=1}^{NG} F_i(P_{gi}) \]  

(1)

Which is the sum of operating cost over all controllable power sources, Where \( F_i(P_{gi}) \) is the generation cost function for generation \( P_{gi} \) at bus \( i \).

NG indicate the number of generation including the slack bus. The individual costs of each generating units are considered being function, only, of active power generation and are showed by quadratic curves of second order. The objective function for the whole power system can be presented as the sum of the quadratic cost model at each generator.

The conventional quadratic fuel cost function of generating units is given by

\[ F_i(P_{gi}) = \sum_{i=1}^{NG} a_i P_{gi}^2 + b_i P_{gi} + c_i \]  

(2)

Where \( P_{gi} \) is the generated active power at bus \( i \). \( a, b, \) and \( c \) are the unit costs curve for generator \( i \).

B. Constraint Equations

1. Unit Operation Constraints can be presented by:

\[ P_{gi}^\text{min} \leq P_{gi} \leq P_{gi}^\text{max} \]  

(3)

Where \( P_{gi}^\text{min} \) and \( P_{gi}^\text{max} \): Lower and upper limit of active power generation at bus \( i \).

2. Power Balance equation:

\[ \sum_{i=1}^{NG} P_{gi} = P_D + P_L \]  

(4)

Where \( P_D \) is the demand and \( P_L \) is transmission loss. The transmission loss calculated by the B-coefficients method.

B-coefficients applied in the power system by:

\[ P_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_{gi} B_{ij} P_{gj} \text{ MW} \]  

(5)

Where \( P_{gi} \) and \( P_{gj} \) are generation at \( i \)th and \( j \)th bus respectively.

\( B_{ij} \) is the Loss coefficient which is constant under certain assumed condition, NG no of generator bus.

III. ANT COLONY OPTIMIZATION ALGORITHM

A. Framework for ant colony system

Entomologists have studied the ability of ants to find the shortest path between their nest and a food source. From these studies, Ant Colony Optimization (ACO) has been developed by Dorigo et al. [1] and successfully employed to solve various optimization problems. ACO is a metaheuristic and evolutionary approach where several generations of artificial ants in a cooperative way search for good solutions. Initially artificial ants move randomly along paths and deposit chemical substance trails, called pheromone, on the ground when they move. And ants collect and store information in pheromone trails during their moving. This pheromone trails motivate them to follow the path with high intensity of pheromone. With time, the pheromone trail is reinforced or evaporated by the move of ants. Finally, all ants can choose the shortest path in their movement [25].

B. Ant colony optimization algorithm

As shown in Fig. 1, the agents (i.e. ants) are guided by the intensity of pheromone trails. The path rich in pheromone becomes the best tour with time. This concept inspired the ACO algorithm. Initially, each agent is positioned on a starting node. Agents move to feasible neighbor nodes following the state transition rule. This rule indicates the preference of ants in choosing their paths that connect the current node to the next node. During the moving process, ants modify the level of pheromone on the paths they choose by applying the local updating rule. If the pheromone level on the chosen paths is lowered, these paths become less attractive to other agents. This property gives agents a higher probability to explore different paths and find an improved solution. Once all agents have reached the final node and have identified the best path which has the optimal value of the objective function, they update the pheromone level on the best path by applying a global pheromone updating rule. This is intended to allocate a higher level of pheromone on the best path. The rules to find the best path are detailed as below [13]:

State Transition Rule.

This rule guides the agents’ search toward neighbor nodes stochastically. The k-th agent at time t positioned on node r move to the next node u along the shorter path with higher intensity of pheromone \( \tau_{ru}(t) \).

\[
\text{S}=\begin{cases} 
\arg\max_k [\tau(r,u)]^{[\eta(r,u)]^\beta}, & \text{if} \ q \leq q_0(\text{exploration}) \\
\text{S, otherwise(Bisedexploitation)} 
\end{cases}
\]  

(6)

Where,
\( \tau_{in}(t) \): The pheromone trail at time \( t \).

\( \eta_{in}(t) = 1/TrsC(t) \): the inverse of the transition cost.

\( TrsC(t) \) with \( r-s \) being the path from node \( r \) at the current stage to node \( s \) at the next stage.

\( \alpha, \beta \): parameters representing the relative importance \( q \): a random number uniformly distributed in \([0,1]\).

\( q0 \): a pre-specified parameter \((0 \leq q0 \leq 1)\).

\( allowed k (t) \): the set of feasible nodes currently not assigned by the ant \( k \) at time \( t \).

\( S \): an index of node selected from \( k(t) \) allowed according to the probability distribution given by (7).

\( P_{k}(r, u) = \begin{cases} [\tau(r,u)^{\alpha}\eta(r,u)^{\beta}] & \text{if } s \in J(k) \setminus \{r\} \\ 0, \text{otherwise} \end{cases} \) \( J_{k}(r) \): set of nodes that remain to be visited by ant \( k \) to make the solution feasible.

Local Updating Rule.

An ant changes the pheromone level on the moved path (local updating) by applying the local updating rule (8). This rule has the effect of lowering the pheromone level on the search paths.

\[ \tau(r,s) \leftarrow (1 - \rho) \tau(r,s) + \rho \cdot \tau_0 \] \( \rho \): evaporation coefficient \((0 < \rho < 1)\).

\( \tau_0 \): initial pheromone level, \( \tau_0 = 1/J \) where \( J \) is a rough approximation of the optimum value of the cost function.

Global Updating Rule.

The global pheromone updating is performed only after all ants have completed their moving. The global pheromone updating rule (9) is intended to provide a greater amount of pheromone to shorter path.

\[ \tau(r,s) \leftarrow (1 - \alpha) \cdot \tau(r,s) + \alpha \cdot \Delta \tau(r,s) \] \( \alpha \): pheromone decay coefficient \((0 < \alpha < 1)\).

\( \Delta \tau_{re} \) is the visibility. In the classical problem TSP this is defined as the inverse of the distance between two cities, \( n_{ij} = 1/d_{ij} \).

\( \alpha \) and \( \beta \) are parameters that control the relative importance of pheromone intensity versus visibility.

So, it could be used here the inverse of the cost for the particular power level:

\[ n_{ij}(t) = \frac{1}{F_i(P_y)} \] \( F \) is the objective function.

IV. ACO APPLIED TO ECONOMICAL LOAD DISPATCH

Description of algorithm

For every generator the area of its power limits is divided in discrete values. The division can be done in various ways. In this we can divide all fragments in equal number of sub-fragments. So far, every generator we have done did not have a continuous fragment of power but discrete definite set depending on the separation that has taken place.

\[ \tau_{ij}(t) = (1 - \rho) \tau_{ij}(t) + \Delta \tau_{ij}(t) \] \( \rho \): the coefficient representing pheromone persistence \((0 \leq \rho < 1)\), and \( \Delta \tau_{ij} \) is a function of the solutions found at iteration \( t \), and it is algorithm specific.
\[ \Delta \tau_{ij} = \sum_{k=1}^{n} \Delta \tau_{ij}^k(t) \]  \hspace{1cm} (13)

\( \Delta \tau_{ij}^k \) is the quantity per unit of length of pheromone addition laid on edge \((i,j)\) by the \(k\)th ant at the end of iteration \(t\), is given by:

\[
\Delta \tau_{ij}^k(t) = \begin{cases} 
\frac{Q}{L^k(t)}, & \text{if } (i,j) \in T^k(t) \\
0, & \text{if } (i,j) \notin T^k(t)
\end{cases}
\]  \hspace{1cm} (14)

Where \( L^k(t) \) is the tour done by ant \(k\) at iteration \(t\)

\( Q \) is a constant parameter, used for defining to be of high quality solutions with low cost.

**B. The Algorithm for solution**

Step 1: Define (discrete) power for every generator. For every generator and for every power level we calculate the visibility.

Define the pheromone, giving it a large value, in all edges that connect every generator with the power level respectively. Define the total number of ants and the number of iterations.

Step 2: For every ant and for every generator select a power level based on random-proportional transition rule as according to equation (10).

Step 3: Calculate the cost for all ants based on the division of power levels which is based on objective functions and \(a, b,\) and \(c\) are the unit costs curve and save the best.

Step 4: Renew pheromone using pheromone update rule according to specified ant algorithm and the equation (12, 13 and 14).

Step 5: Repeat the procedure from step 2 until a specific number of iterations are completed or all the ants preceding the same path.

**V. SIMULATION RESULT AND DISCUSSION**

**A. Test system: IEEE 26-bus system [6]**

The Proposed algorithm is tested on the standard IEEE 26 bus test system. This system is having 26 buses and 6 generators. Total demand is 1263 MW. Fig 3 shows the Line Diagram of IEEE-26 bus system.

Four parameters of the colony of ants \(\alpha, \beta, \rho\) and \(q_0\) is extensively independent of the problem of optimization to solve, developed algorithm is tested on the network IEEE 26 buses while using the 10 better combinations of the three parameters \(\beta, \rho\) and \(q_0\) and that give the best results for commercial traveler problem for the case of 30 cities [9].

**Table 1:** Cost Coefficients and Generator Limits [6]

<table>
<thead>
<tr>
<th>Generator No</th>
<th>Cost Coefficient</th>
<th>MW Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a)</td>
<td>(b)</td>
</tr>
<tr>
<td>1</td>
<td>0.0070</td>
<td>7.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0095</td>
<td>10.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0090</td>
<td>8.5</td>
</tr>
<tr>
<td>4</td>
<td>0.0090</td>
<td>11.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0080</td>
<td>10.5</td>
</tr>
<tr>
<td>6</td>
<td>0.0075</td>
<td>12.0</td>
</tr>
</tbody>
</table>

**Table 2.** Transmission loss co efficient matrix are given as

\[
B = \begin{bmatrix}
0.0017 & 0.0012 & -0.0007 & -0.0001 & -0.0005 & -0.0002 \\
0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\
0.0007 & 0.0009 & 0.0031 & 0.0000 & -0.0010 & -0.0006 \\
-0.0001 & 0.0001 & 0.0000 & 0.0024 & -0.0006 & -0.0008 \\
-0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\
-0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150
\end{bmatrix} \text{ MW-1}^{-1}
\]

**B. Results for Test system**

Various combinations of four parameters \(\alpha, \beta, \rho\) and \(q_0\) that give the best results for commercial traveler problem for the case of 30 cities.

The economical value of the cost is 15444.0 $/h corresponds to losses of powers 12.35MW.

The obtained minimum cost results are compared with those results which are there in literature.

**Table 3.** Comparison in Minimum cost and Losses

**VI. CONCLUSION**

In this paper, an Ant Colony Optimization approach to the Economical Load Dispatch problem is introduced and tested. As a study case, the IEEE 26 Bus system with three generating units has been selected with smooth cost functions, the simulation results show that for medium-scale system an ant colony optimization method can give a better
results. The developed algorithm is able to minimize the generation cost while meeting the demand requirement. Obtained results are also compared with established algorithms like SA, GA, PSO etc. which are reported in literature comparison shows that developed technique is efficient compared to others. Further development in technique may help to solve dispatch problems with prohibiting operating zones as well as environmental constraints and unit commitment problems.

REFERENCES