AN EFFICIENT IMPROVED ANT COLONY OPTIMIZATION TECHNIQUE TO SOLVE COMBINED ECONOMIC AND EMISSION DISPATCH PROBLEM

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Abstract: *Power systems have become vast and their analysis has become a complicated problem in recent years. Providing a best solution for meeting the varying demand for electricity is one of the major issues of the electric power generating organizations. The aim of power system optimization problem is to effectively schedule the generating units over a given scheduling period while meeting the projected load demand, satisfying various operating constraints and meeting certain objectives. The objective of the power system optimization can be expressed by taking both the fuel cost and total emission into account with specified constraints. The Combined Economic and Emission Dispatch problem (CEED) is defined to minimize the fuel cost of generation and the emission of green house gases of the thermal generating stations satisfying all the system constraints which makes the problem multi-objective. The multi-objective problem is converted into single objective problem by introducing price penalty factor to maintain an acceptable system performance. There are various techniques developed by a number of researchers to solve CEED problem based on optimization techniques. But still some problems like slower convergence and higher computational complexity exists in using the optimization techniques like GA for solving CEED problem. This paper proposes an efficient and reliable technique for combined fuel cost economic optimization and emission dispatch using the Improved Ant Colony Optimization algorithm (IACO) to produce better optimal solution. The simulation results reveal the significant performance of the proposed IACO approach.*

Keywords: *Combined Economic Emission Dispatch (CEED), Optimization Algorithms, Power Demand, Ant Colony Optimization, Improved Ant Colony Optimization (IACO).*

1. INTRODUCTION

The main objective of the electric power system is to provide high-quality, reliable power supply to the consumers at a lowest possible cost [1]. This is possible by finding an optimal combination of the output power of all the online generating units (i.e Economic Dispatch) that minimizes the total fuel cost, satisfying set of equality and inequality constraints. In the recent years, with an increasing awareness of the environmental pollution caused by thermal power plants, limiting the emission of pollutants is becoming a crucial issue in power system [2]. The conventional economic power dispatch cannot meet the environmental protection requirements, since it considers minimizing the total fuel cost alone. The multi objective generation dispatch in electric power systems treats economic and emission impact as competing objectives, which require some reasonable tradeoff among objectives to reach an optimal solution. This formulates the Combined Economic and Emission Dispatch (CEED) problem with an objective to dispatch the electric power considering both economic and environmental aspects. New approaches using intelligent technique are proposed to solve a CEED problem with minimizing the fuel cost and less emission by satisfying the equality and inequality constraints.

The Genetic Particle Swarm Optimization (GPSO) to overcome the economic dispatch difficulty in power system. GPSO was derivative of the Standard Particle Swarm Optimization (SPSO) and combined with the genetic reproduction techniques called crossover and mutation [3]. An altered heuristic crossover was developed that was obtained from the differential evolution and genetic algorithm together with the technique of GPSO. Additionally, to have a better result other PSO was utilized to a practical system, and by assessment with the Modified Genetic Particle Swarm Optimization (MGPSO).

Genetic Algorithm (GA) is one of the significant optimization algorithm used to solve CEED problem [4], [12]. But, GA suffers from slower convergence rate and higher computational cost which would affect the overall performance. More recently, Ant colony algorithms which were inspired by the observation of real ant colonies are observed to provide better optimized results than GA.

This paper uses Improved Ant Colony Optimization (IACO) approach to reduce the total system operating cost and emission levels. To anticipate the pollutant problem, the proposed IACO algorithm contains two objective functions, i.e. economic objective function (fuel cost and transmission losses) and emission objective function.

2. METHODOLOGY

Economic Dispatch

The economic dispatch problem is to determine the optimal mixture of power generation in a manner that the entire production cost of the entire system is reduced while satisfying the total power demand and few key power system factors. Initially, the fuel cost for all the power generation units has been defined. The total production cost function of EDP is defined as the total sum of the fuel costs of all the generating plant units as mentioned below [5]

$$F_T = \sum_{i=1}^{N_G} \left\{ a_i P_i^2 + b_i P_i + c_i + \left| d_i \sin e_i \left(P_i^{min} - P_i \right) \right| \right\} \quad (1)$$

Where, e_i and d_i are the fuel cost coefficients of unit i with valve-point effect. Now, the modified objective function for the ED problem is to minimize F_T given in Equation (1). This equation helps in determining the total production cost of the generating plant, subject to the following equality and inequality constraints.

Emission Dispatch

The solution of economic dispatch problem will provide the quantity of active power to be produced by various units at the minimum production cost for a certain power requirement. On the other hand, the total quantity of pollutant emission is not considered in conventional economic dispatch problem. The quantity of pollutant emission resulted from a fossil-fired thermal generating unit is based on the amount of power generated by every unit. For reducing the complexity, the total emission produced can be modeled as a direct sum of a quadratic function and an exponential term of the active power output of the generating units. The pollutant emission dispatch problem can be described as an optimization of total amount of pollutant emission given below [5].

$$E_T = \sum_{i=1}^{N_G} \left\{ \alpha_i P_i^2 + \beta P_i + \gamma_i + \xi_i e^{\tau_i P_i} \right\} \quad (2)$$

where

E_T is the total pollutant emission (lb/hr)

N_G is the total number of generating units

P_i is the power output of generating unit i

α_i β_i ξ_i γ_i τ_i are emission coefficients of unit i

Combined Economic and Emission Dispatch

The economic dispatch and emission dispatch are two various problems as discussed previously. Emission dispatch can be included in conventional economic load dispatch problems by merging an emission constraint with the economic load dispatch problem [6]. In this paper, the two objectives can be converted into a single objective function by introducing a price penalty factor as defined follows.

$$h = \frac{F_T(P_i^{max})/P_i^{max}}{E_T(P_j^{max})/P_j^{max}} \tag{3}$$

Where

h is the price penalty factor

i is the highest fuel-cost unit

j is the highest pollutant-emission unit

The price penalty factor h combines the emission with fuel cost and the fuel cost is the total operating cost in US dollars per hour. The price penalty factor h is the ratio between the maximum fuel cost and maximum emission of corresponding generator [7].

The following steps are used to find the price penalty factor for a particular load demand.

- Identify the ratio between maximum fuel cost and maximum emission of each generator.
- Arrange the values of price penalty factor in ascending order.
- Add the maximum capacity of each unit one at a time, starting from the smallest h unit generated value is greater than demand.
- At this stage h associated with the last unit is the price penalty factor h for the given load.

The combined objective function of the economic and emission dispatch is represented by the following equation:

$$\Phi_T = w_{eco}F_T + w_{emi}hE_T \tag{4}$$

Where

Φ_T is the combined objective function

w_{eco}, w_{emi} are weighting factors.

The two weighting factors can be provided in various ways. The case of w_{eco} = 1.0 and w_{emi} = 0.0 is to obtain the classical economic dispatch problem and the pure emission dispatch is resulted when w_{eco}, = 0.0 and w_{emi} = 1.0. In this case, h obtained from the procedure is used. To obtain the combined economic and emission dispatch problem, both weighting factors should be equal, for example w_{eco}, = 0.5 and w_{emi} = 0.5. It means that, both the conditions are satisfied in this scenario to obtain the optimal results.

Problem constraints

Usually, there are two constraints such as equality and inequality constraints should be considered. For the problem defined in this paper, a power balance equation (5) is set as an equality constraint and the limits of power generation output (6) are set as inequality constraints.

$$P_D + P_{Loss} - \sum_{i=1}^{N_G} P_i = 0 \tag{5}$$

where F_T is the total fuel cost of the system, P_i is the power output of generating unit *I*, *i=1,2, …N; N* indicates the number of generators,

$$P_i^{min} \leq P_i \leq P_i^{max}, i = 1,2, \ldots, N_G \tag{6}$$

Where

P_D is the total power demand of the plant

P_{Loss} is the total power losses of the plant

P_i^{min} is the minimum output of generating unit *i*

P_i^{max} is the maximum output of generating unit *i*

P_{Loss} is the system transmission losses, which is approximated in terms of B coefficients as

$$P_{Loss} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j \tag{7}$$

B_{ij} is the B coefficients or the loss coefficients.

With this defined problem and objective function, an appropriate optimization technique is used to obtain the required objective. This paper uses Improved Ant Colony optimization technique which has various advantages over the existing system which uses conventional optimization techniques to solve the CEED problem.

3. IMPROVED ANT COLONY OPTIMIZATION

In this paper, a improved ACO is presented which aims at directing the ants' search towards higher quality solutions and avoid premature convergence to exploit stronger solutions during the search.

ACO algorithms can be enriched with additional capabilities to improve the efficiency and efficacy of the system. For example, the improvements are made by updating pheromones, changing evaporation coefficient or the amount of released pheromones in order to avoid stagnation. In this work the improvements are made by updating pheromones and the new updated pheromone equation is given below.

Pheromone update: Let τ_{ij}(new) be the intensity of the trail on edge (i,j) at time t. After initialization/first iteration/n iterations of the algorithm the trail intensity becomes,

$$\tau_{ij}(\text{new}) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij}^{opt} \quad (8)$$

Where,

$$\Delta\tau_{ij}^{opt} = \begin{cases} \dfrac{(f_{ij_c}^2 - f_{ij_b}^2)\times(f_{ij_c}^2 - f_{ij_a}^2)}{\left|f_{ij_c} - f_{ij_b}\right| + \left|f_{ij_c} - f_{ij_b}\right|} & if\,(i,j)\in F \\ 0 & otherwise \end{cases} \quad (9)$$

Where ρ is a evaporation rate,

F – fitness function

$\Delta\tau_{ij}^{opt}$ - required optimal trail/path for ant x.

f_{ij_a} - fitness value of current ant

f_{ij_b} - fitness value of local best ant

f_{ij_c} - fitness value of global best node found by ant

In the existing algorithm [8], pheromone update is a function of scalar distance travelled by the ants between the nodes, whereas in the proposed algorithm pheromone updation is a function of vector distance travelled by the ants between the nodes. The graphical representation of proposed pheromone update function is shown in Figure 1.

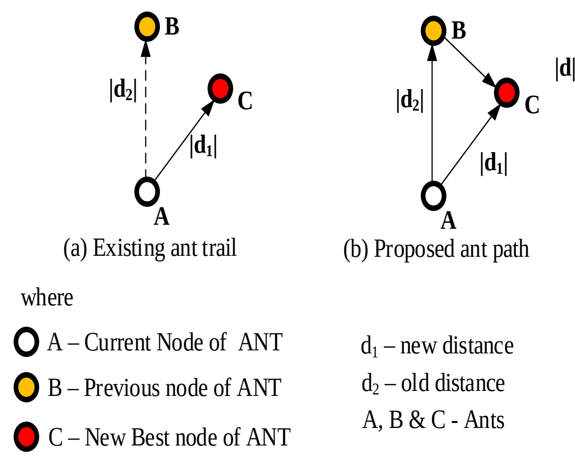


Figure 1 Graphical representation of pheromone update function

As from the figure, updated global distance is not in the same direction as previous global best location C-A can't be a function not in the same direction that of previous global best, whereas proposed equation is function of the direction as well as magnitude of distance travelled by ant which increases the better convergence of the algorithm. Finally, the optimized parameters will be used in achieving the solution for combined economic and emission dispatch problem. Algorithm for IACO is shown in Figure 2

The ant algorithm system is characterized by a number of controlling parameters such as the sensitivity to the pheromone concentration (α), the sensitivity to cost of the path (β), the number of iterations of the algorithm and the number of ants used per iteration. In the transition probability rule, best results have been found when both α and β values are approximately in the same range but there was a problem found when the range of the pheromone value and visibility value are far from each other. So, in this case the parameters α and β are selected in such a way to that near the range of pheromone values and visibility values are closer from each other. This approximation can be found in the exp(x) and 10 log (x) functions, where x is any value.

The first modified transition probability can be written as:

$$Ep_{ij}^{k}(t)=\begin{cases}\dfrac{\exp(\tau_{ij}^{k}(t))*\exp(\eta_{ij}(t))}{\sum\exp(\tau_{ij}^{k}(t))*\exp(\eta_{ij}(t))} & u\in allowed\\ 0 & otherwise\end{cases} \quad (10)$$

The exponential function is featured by its large rate increase in values. This characteristic feature can be used to obtain the best result rapidly. The second modified transition probability can be written as:

$$Lp_{ij}^{k}(t)=\begin{cases}\dfrac{\log_{10}(1+\tau_{ij}(t))*\log_{10}(1+(\eta_{ij}(t))}{\sum\log_{10}(1+\tau_{iu}(t))*\log_{10}(1+(\eta_{iu}(t))} & u\in allowed\\ 0 & otherwise\end{cases} \quad (11)$$

The logarithmic function is characterized by converting a large range of values to a small range of values, so that the two parameters α and β are not required. Here any one of the above two equations is used. It will reduce the control parameters by eliminating the parameters α and β and at the same time reducing the number of Ant Algorithm iterations which result in increasing the system performance as discussed in [9]. Finally, the optimized parameters will be used in achieving the solution for combined economic and emission dispatch problem.

4. RESULTS AND DISCUSSION:

Test systems are widely used in power system research and education. The reasons for using test system rather than using practical system are as follows:

- Power systems data are generally confidential.
- Dynamic and static data of the systems are not well documented.
- Calculations of numerous scenarios are difficult due to large set of data.
- Lack of software capabilities for handling large set of data.
- Less generic results from practical power system.

1. Procedure Improved_ACO
2. begin
3. Initialize the pheromone
4. while stopping criterion not satisfied do
5. Position each ant in a starting node
6. Repeat
7. for each ant do
8. Chose next node by applying the modified exponential and logarithmic state transition rate

$$Ep_{ij}^{k}(t)=\begin{cases}\dfrac{\exp(\tau_{ij}^{k}(t))*\exp(\eta_{ij}(t))}{\sum\exp(\tau_{ij}^{k}(t))*\exp(\eta_{ij}(t))} & u\in allowed\\ 0 & otherwise\end{cases}$$

$$Lp_{ij}^{k}(t)=\begin{cases}\dfrac{\log_{10}(1+\tau_{ij}(t))*\log_{10}(1+(\eta_{ij}(t))}{\sum\log_{10}(1+\tau_{iu}(t))*\log_{10}(1+(\eta_{iu}(t))} & u\in allowed\\ 0 & otherwise\end{cases}$$

9. end for
10. until every ant has build a solution
11. Update the pheromone

$$\tau_{ij}(new)=(1-\rho)\tau_{ij}(t)+\Delta\tau_{ij}^{opt}$$

$$\Delta\tau_{ij}^{opt}=\begin{cases}\dfrac{(f_{ij_c}^2-f_{ij_b}^2)\times(f_{ij_c}^2-f_{ij_a}^2)}{\left|f_{ij_c}-f_{ij_b}\right|+\left|f_{ij_c}-f_{ij_b}\right|} & if\,(i,j)\in F\\ 0 & otherwise\end{cases}$$

12. end while
13. end

Figure 2 Algorithm for IACO

The proposed research work for solving the CEED problem using optimization algorithms is evaluated in MATLAB 7.0. The proposed approaches for solving CEED have been tested a Six – Generator. Input data for all the test systems are taken from [4]. The resulted CEED solution for the considered six-generator system is presented in Table 1. From the table, it is observed that the proposed IACO approach produced optimum CEED solution compared with MODE solution for six generator system.

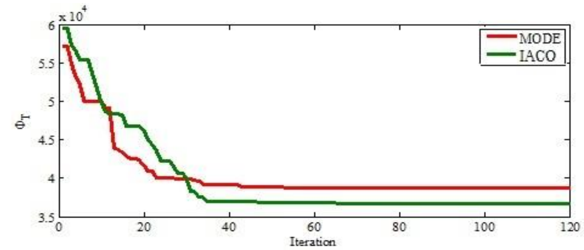
Table 1 CEED Solution of Six-Generator System

Generation Unit	MODE Power Demand in MW			IACO Power Demand in MW		
	800	1000	1200	800	1000	1200
Unit 1	52.23	75.21	105.75	46.23	73.45	116.63
Unit 2	78.96	107.01	107.33	76.14	103.36	115.44
Unit 3	109.16	143.65	208.42	109.21	136.75	199.11
Unit 4	162.91	187.64	202.67	166.14	189.74	220.01
Unit 5	198.79	232.41	313.30	197.17	243.25	293.68
Unit 6	224.12	285.96	317.87	224.29	276.40	298.41
Fuel Cost ($/hr)	42715	53249	64852	42317	52707	63908
Emission Output (lb/hr)	825	968	1278	724	866	1257

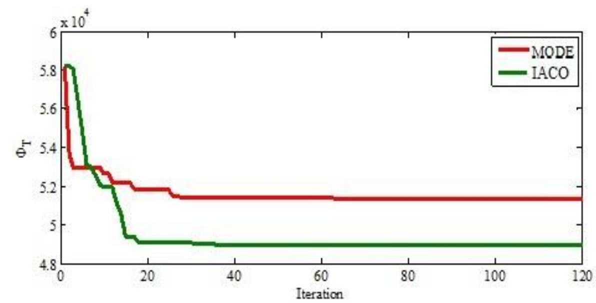
Table 2 Comparison of Fuel Cost ($/hr)

Optimization Technique	Approach	Power Demand (MW)		
		800 (MW)	1000 (MW)	1200 (MW)
DE [10]	**Economic Dispatch (Single objective)**	42693	51153	61215
MODE [11]	**CEED (Multi objective)**	42715	53249	64852
IACO	**CEED (Multi objective)**	**42317**	**52707**	**63908**

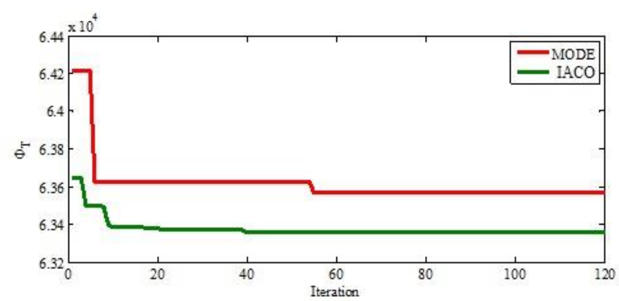
The fuel cost required for a particular power demand and the resulted emission output by using the proposed IACO technique is presented in Table 2. The proposed IACO technique is compared with the results of single-objective Differential Evolution (DE) and Multi-Objective Differential Evolution (MODE). The fuel cost required by various approaches as shown in Table 2. The table values shows the results is obtained for single-objective DE produced for Economic Dispatch cost only, whereas the Multi-objective DE and IACO produced the cost for combined Economic and Emission Dispatch (CEED). From the observation, it can be clearly suggested that the proposed IACO technique is produced best optimum value compared with MODE. The convergence of IACO and MODE responses of six generator system is shown in Figure 3.



(a)



(b)



(c)

Figure 3 CEED solution comparison of six generator system with MODE and IACO a) 800 MW, b) 1000 MW and c) 1200 MW

Table 3 shows the emission output of the approaches such as DE, MODE and IACO for three different power demands. The emission resulted for using the proposed IACO optimization technique is very less when compared with the other techniques. This case is true not only for a particular power demand but rather it is true for all cases.

Table 3 Comparison of Emission Output (lb/hr)

Optimization Technique	Approach	Power Demand (MW)		
		800 (MW)	1000 (MW)	1200 (MW)
DE [10]	**Economic Dispatch (Single objective)**	548.96	846.25	1174.20
MODE [11]	**CEED (Multi objective)**	825	968	1278
IACO	**CEED (Multi objective)**	**724**	**866**	**1257**

Also, the power loss is lesser for the proposed approach which is indicated in Table 4. It is clearly observed from the Table 4 that the power losses for the proposed IACO approach is less for all the power demand constraints.

Table 4 Comparison of Power Loss (MW)

Optimization Technique	Approach	Power Demand (MW)		
		800 (MW)	1000 (MW)	1200 (MW)
DE [10]	**Economic Dispatch (Single objective)**	26.19	35.46	48.91
MODE [11]	**CEED (Multi objective)**	23.17	26.88	46.68
IACO	**CEED (Multi objective)**	**19.18**	**22.95**	**41.28**

The number of iterations required for optimization for DE, MODE and IACO is provided in Figure 4. It is observed that the proposed IACO technique requires lesser iterations for optimization when compared to other techniques. Also, the time required for optimization is much reduced for the proposed technique when compared to the other techniques and is shown in Figure 5.

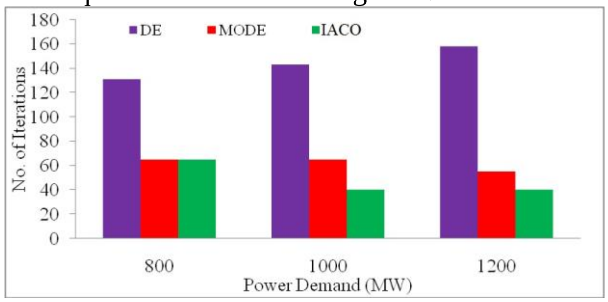


Figure 4 Comparison of Number of Required Iterations

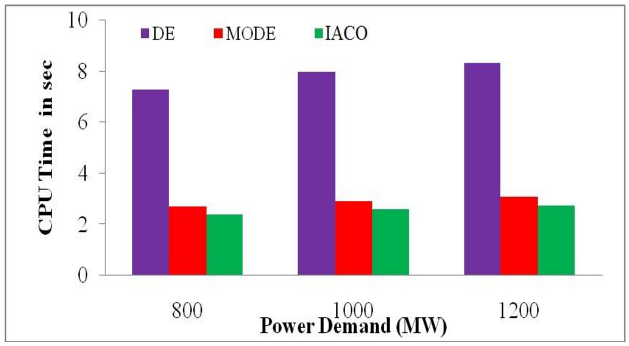


Figure 5 Comparison of Computation Time

5. CONCLUSION:

Optimization algorithms are observed to provide significant results for CEED. In case of lesser cost techniques, there would be increase in the emission of pollution causing elements. Therefore, the cost reduction must be controlled by means of a technique called Emission Dispatch. But, the controlling of emission will increase the cost required for power generation. So, this paper focuses on Combined Economic and Emission Dispatch (CEED) problem solving approach. There are various technique exists to deal with CEED problem which are suggested by various researchers. Widely used technique for CEED problem is to optimize the parameters used for power generation with the help of optimization techniques like PSO, GA, etc. But, all those techniques requires more time for optimization. To overcome those difficulties, this paper uses IACO optimization technique. The simulation result shows the performance of the proposed technique and it can be suggested that the proposed technique reduces the fuel cost as well as the emission output. At the same time, it takes only lesser time and number of iterations for optimization.

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