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Potential Competitive Over Resources (COR) Optimization Method to Solve Economic Load Dispatch Problem

This paper proposes a new method namely Competitive over Resources (COR) optimization algorithm to solve the economy load dispatch (ELD) problem which has the ability to search for a global optimum by considering the operating constraints of the generating units. Similar to many of the recent heuristic optimization techniques based on the behavior of physical or biological systems in nature, the proposed COR optimization method is generally a new evolutionary algorithm inspired by animal behavior competing to finding food resources. In natural competition, the animal in any group will search for the area with abundant food sources. The group that succeeds in locating the abundant food supply experiences an increase in the population and thus exhibits fast convergence toward optimal results. In order to evaluate the performance of the COR algorithm, two standard ELD test systems with considerable constraints have been tested and compared with other published ELD problem using basic heuristic algorithm. Applying the proposed algorithm on ELD function shows its capability to converge nearer to the optimum solution compared to other determined optimization methods.

Keywords: Economic load dispatch (ELD); Competitive over Resources (COR); optimization methods.

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1. Introduction

The economic load dispatch (ELD) for generation in modern power systems is one of the most important optimization problems. Therefore, the solution is a major subject of power system operations and planning. The main objective of the ELD is to encounter the required power demand by scheduled power generation units such that the total cost production is lowest, while at the same time satisfying the equality and inequality constraints of the system. The factors influencing power generation at minimum cost are operating efficiencies of generators, fuel cost and transmission losses. Consequently, the optimal solution of power generation with ELD problem contributes to significant economic benefits of power plant operation.

The simplest model of ELD is presented by a quadratic function that is based on fuel cost of generating units with constraint restricted to the limitation of power generation of units and power balanced between load demand and total power generation. However, in order to simulate the more realistic application on ELD problem, further equality and non-equality constraints are added by introducing the power balance between load and power generation, transmission line losses, prohibited operating zones of the units and ramp rate limits. These additional constraints increase complexity optimization of ELD problem that also increases the non-linear, non-smooth and non-continuous nature of ELD mathematical modelling.

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ELD problem had initially been solved using conventional methods such as linear, nonlinear and quadratic programming techniques. These conventional methods may have difficulties in finding optimal solution due to complex mathematical optimization problem. As an alternative and better solution to conventional ELD problem, a new method has been introduced based on nature inspired meta-heuristic optimization algorithms, such as Genetic Algorithm (GA) [1–4], Particle Swarm Optimization (PSO) [5–7], Firefly Algorithm [8, 9], Artificial Bee Colony (ABC) Algorithm [10, 11], Pattern Search Algorithm, Ant Colony Optimization (ACO) [12, 13], Different Evolutionary (DE) Algorithm, Neural Network (NN) and others. The main goal of this optimization algorithm is to operate to find quality solutions of optimal value (global) and possess the ability to converge to the concerns expressed in the ELD problems.

This paper presents a new evolutionary algorithm namely Competition over Resources (COR) to solve ELD problem inspired by competitive behavior over food resources. Since the simulation is based on practical power system operating conditions, the equality and non-equality constraints that increase the complexity towards finding a global solution are considered. The aim of using COR optimization method to solve ELD problem is to compare the result with other optimization methods in terms of quality of solution and ability of convergence.

The rest of the paper is organized as follows. Section 3 presents the formulation of the ELD problem and its three main components. Section 4 introduces and explains the COR algorithm and its processes. The specific application of COR to ELD problem is presented in Section 5. Test system and configuration is presented in Section 6. Section 7 presents the results and discussion of the simulations and comparison of the proposed COR method to other methods. Finally, conclusive remarks are presented in Section 8.

2. Notation

The notation used throughout the paper is stated below.

Constants:

Ng	total number of generating units in power system
F_j	cost function of the j^{th} generating unit [$/h]
P_j	power generation of the j^{th} generating unit [MW]
P_D	total system demand [MW]
P_L	total power transmission losses [MW]
$P_{POZ,j}$	power generation of the j^{th} generating unit at prohibited operating zones [MW]
$P_{RRL,j}$	power generation of the j^{th} generating unit at ramp rate limit area [MW]

3. Economic load dispatch problem formulation

The ELD problem, which considers the economic issues comprehensively, is referred to allocate the combination of load dispatch from all generators. The mathematical optimization for ELD has three main components: optimization variable of the problem, goal of objective function and constraints.

3.1. Optimization variable

The input variable to be optimized is the real output power of generating units:

$$P = \left[P_1, P_2, P_3, \ldots\ldots, P_{Ng} \right] \tag{1}$$

3.2. Objective function

The goal of objective function is to reach minimum total fuel cost produced by each generator unit. The objective function of ELD can be presented by mathematical optimization function given below:

$$\text{minimize } F_{cost} = \sum_{j=1}^{Ng} F_j \left(P_j \right) \tag{2}$$

In addition, cost function of each generating unit is defined by the following quadratic equation

$$F_j \left(P_j \right) = \alpha_j + \beta_j P_j + \gamma_j P_j^2 \tag{3}$$

where α_j, β_j and γ_j is the coefficients of the j^{th} generating unit.

3.3. Constraint

In order to reach optimum value of ELD, the objective function is subjected to the following equality and inequality constraints:

3.3.1. Real power balance

The total power generation must be equal to the sum of total system demand (P_D) and transmission losses (P_L), given as follows:

$$\sum_{j=1}^{Ng} P_j = P_D + P_L \tag{4}$$

The total transmission losses can be calculated using Kron's loss equation following:

$$P_L = \sum_{j=1}^{Ng} \sum_{k=1}^{Ng} P_j B_{jk} P_k + \sum_{j=1}^{Ng} P_j B_{j0} + B_{00} \tag{5}$$

where B_{jk}, B_{j0} and B_{00} is the B-coefficients or loss coefficient.

3.3.2. Generation limit

The power generated by each generator must be within their maximum and minimum operating limits as follows:

$$P_j^{min} < P_j < P_j^{max} \tag{6}$$

where P_j^{min} and P_j^{max} is the minimum and maximum generation limit of generator in MW.

3.3.3. Prohibited operating zones

Due to physical limitations on components and vibration of steam valve in a shaft bearing, the system contains some prohibited zones.

$$\begin{aligned} &P_{POZ,j}^{min} \le P_{POZ,j} \le P_{POZ,j,1}^{l} \\ &P_{POZ,j,k-1}^{u} \le P_{POZ,j} \le P_{POZ,j,1}^{l},\ k = 2,3,\ldots,n_j \\ &P_{POZ,j,n_j}^{u} \le P_{POZ,j} \le P_{POZ,j}^{max} \end{aligned} \tag{7}$$

where $P_{POZ,j,k}{}^{l}$ and $P_{POZ,j,k}{}^{u}$ is the lower and upper bound of k^{th} prohibited zones of the j^{th} generating unit while n_j is the number of prohibited zones of the j^{th} generating unit.

3.3.4. Ramp rate limits

In the actual operating process of generating unit, the operating range of all on-line units is restricted by their ramp rate limits.
If power generation increase:

$$P_{RRL,j} - P_{RRL,j}{}^{0} \le UR_j \tag{8}$$

If power generation decrease:

$$P_{RRL,j}{}^{0} - P_{RRL,j} \le DR_j \tag{9}$$

where UR_j and DR_j is the up and down ramp limit of the j^{th} generator (MW/h) while $P_{RRL,j}{}^{0}$ is the previous output power generator (MW).

Combination of generation limits and ramp up limits can be expressed in equality constraint as below:

$$\max\left(P_{RRL,j}{}^{min}, P_{RRL,j}{}^{0} - DR_j\right) \le P_{RRL,j} \le \min\left(P_{RRL,j}{}^{max}, P_{RRL,j}{}^{0} - UR_j\right) \tag{10}$$

4. Proposed COR algorithm

4.1. Nature inspired behavior

The Competitive Over Resources is a new meta-heuristic algorithm introduced by S. Mohseni, R. Gholami, N. Zarei and A. R. Zadeh in 2014 [14] inspired by competitive behavior of animal groups to search for richer resources at the end of seasons. COR algorithm has been well tested for quality performance by solving different optimization problems in the literature [14–16]. This algorithm is used to test 8 different benchmark functions and it is concluded that this algorithm seeks globally optimum solution much better than the GA and PSO methods.

One of the most important factors in controlling the animal society is competition along with resources, disruption, foraging and mutualism. Short-term ecological interactions will lead to an abundance of species of life throughout the seasons, years or a lifetime. The nature of COR basically starts with the division of the group at the beginning of each year in which each group has its own territory with its own food supply. At this point, each individual group looks for a source of food in its own territory. From time to time along the process, a strong competitor will eliminate the weaker competitors from the same area and the final process ends up only having great competitors. When food sources are depleted or diminished in a particular area, the group's members will also be reduced. Members may move out to join the groups in areas with abundant food sources. Finally, at the end of the year, the group that has less resources is eliminated.

4.2. COR algorithm

Figure 1 shows the flowchart of the COR algorithm. The proposed COR algorithm is population based similar to other meta-heuristic methods. Started with the initialization process of COR optimization algorithm, n number of agents randomly search and identify the source of food.

After initialization process, the objective function is used to evaluate fitness of each corresponding agent. Then, the complete population of agents is ranked and divided into number of groups, where each group will determine the best searching agent referred to as group best. Group best perhaps has a higher chance of surviving. Since technically every group has a chance of surviving however these best groups have a higher probability.

Following this procedure, new territory is to be defined for each group that is measured distance between group best agents using Euclidean distance equation. With every group defined for their territory, next step is to generate new random search agent based on defined territory at inner and outer space of group boundary. With this new random agent, the fitness of each agent is re-evaluated and the best agent of each group is redefined.

The selected best groups will then increase by adding one agent of the group population and the worst group will eliminate one agent of the group population on it. Therefore, it shows that the group starts with equal number of agent and during the following iteration process, the group with the best and worst agent will reflect increasing and decreasing number of agents in the group population. Total size of population agent will remain constant, but only changes the size among groups in which some groups will be stronger and others weaker.

When the number of agent in the weakest group reaches the predetermined rate of death (d_{rate}), this group will be terminated. Simultaneously two new groups will be formed by separating number of agents equally from the strongest group. The second best agent of the best group is taken to form a new group and lead as the new best group operating in the same role as other groups. The complete process is repeated, beginning at determination of new territory of each group until stopping criteria have been met.

From COR algorithm operation, the competition over resources is applied among all groups where any group with good resources and increase in its population will survive until the end season, while the weaker group will be eliminated from the competition. The stronger group will increase in population that will give them more search agents.

At last, dividing the famous groups will minimize the group territory border that will produce flexibility on boundary size and increase the potential of exploration. The exploitation process of algorithm can be done using elimination of worst groups due to population reduction agent of weaker group during this process. This complete process will help group best agents to find quality solution of global area and not get trapped in a local minima.

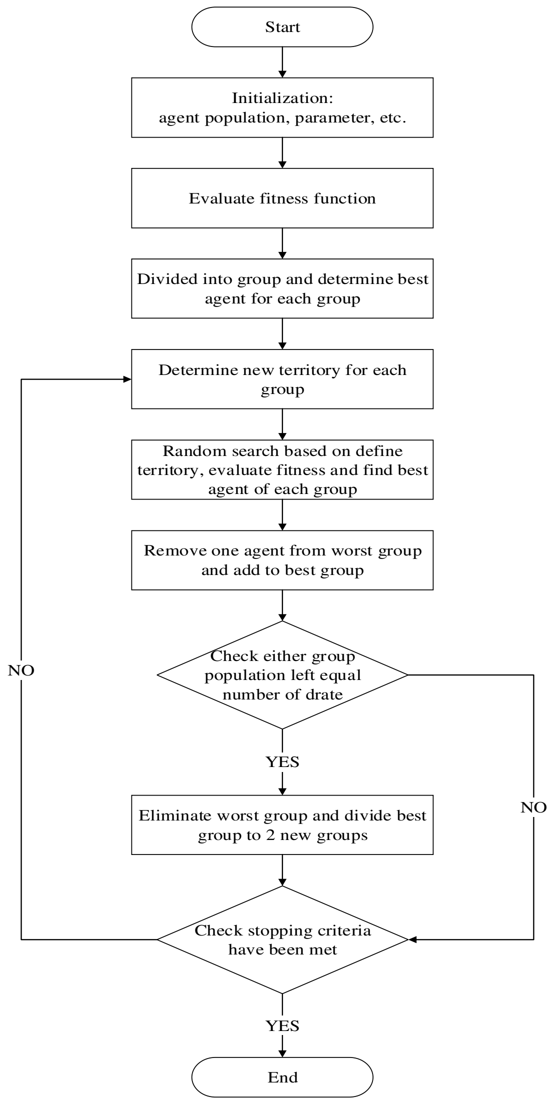

Figure 1 Flowchart of COR algorithm

5. The COR optimization algorithm for ELD

Figure 2 below shows pseudo code of implementation of COR optimization algorithm for solving ELD problem:

```
Initialization of COR parameter
Generate random population of Pg
Evaluation of cost function
Select best agent of each group
while (iter < maximum number of iteration)
   Calculate Euclidian distance between group agent to determine territory for each group
   Generate random search inner and outer individual agent in the territory
   Evaluate new fitness
   Rank agent in each group and record new best agent
   Add agent from best group and remove agent from worst group
   if (group population = d_rate)
        Eliminate worst group and divide best group in two group
   end if
end while
```

Figure 2 Pseudo code for COR optimization algorithm

5.1. Initialization of the COR parameter

Specify the COR parameters such as generation maximum (P_{max}) and minimum (P_{min}) limit of each units, number of population (N_{pop}), number of iteration (N_{iter}), number of groups (N_{group}), outer searching factor (D_{sch}), rate of death (d_{rate}) and population ratio between inner/outer neighborhood (P_{sch}). The active power output of the generator is defined as an input variable for ELD problem.

5.2. Generate random population of *Pg*

The population of power generator for each units, *Pg* (MW) with size of population, N_{pop} is randomly generated between determined generator limits as stated in (6). This initial location of agent can be determined using (11).

$$X_{ij} = X_{j,\min} + \left(rand\left(0,1\right) x \left(X_{j,\max} - X_{j,\min} \right) \right) \tag{11}$$

where $X_{j,max}$ and $X_{j,min}$ is the maximum and minimum value of *j* component while X_{ij} is j^{th} component of *i* solution vector at iteration zero.

5.3. Evaluation of cost function and selection of best agent

The fitness value of each individual population is calculated using (12), which is referred as the combination between objective function equation in (2) and penalty factor associated with related constraints. The objective of using this evaluation function is to gain lowest value of cost generation while satisfying the equality and non-equality constraint problem as stated on (4) – (10).

$$f(P_j) = \sum_{j=1}^{Ng} F_j\left(P_j\right) + k_1 . \left| \sum_{j=1}^{Ng} P_j - \left(P_D + P_L\right) \right| + k_2 . \sum_{j=1}^{Ng} P_{POZ,j} + k_3 . \sum_{j=1}^{Ng} P_{RRL,j} \tag{12}$$

The result from calculation of fitness value has been ranked from the best solution to the worst. Using this ranking, the agents have been divided equally into decided number of groups, N_{group} where for each group the best solution has been identified as the best group agent.

5.4. Determination of territory

Territory of each group has been defined using Euclidean distance between the best group agents. The minimum value of distance between territories, d^{min} has been selected and the value is used to specify maximum and minimum inner territory using (13).

$$\begin{aligned} P_{inner}^{\min} &= P_j - d^{\min} \\ P_{inner}^{\max} &= P_j + d^{\min} \end{aligned} \tag{13}$$

The maximum and minimum outer territory of search space area for each group is determined by using (14).

$$\begin{aligned} P_{outer}^{\min} &= P_j - \left(d_{sch} \times l\right) \\ P_{outer}^{\max} &= P_j + \left(d_{sch} \times l\right) \end{aligned} \tag{14}$$

where l is the difference value between P_{max} and P_{min} and d_{sch} is decision value of searching capability in outer space between values 0 and 1.

5.5. Generate and evaluate new population

The amount of population between inner territory and outer territory for each group needs to be decided using ratio between inner and outer neighbourhoods, P_{sch}. Some amount of the new population of agent in the group has been generated randomly using inner territory to find potential optimum area in group boundary. Then, the remaining of agents are generated randomly with more extensive searching area using defined outer territory to increase the chances of random agent finding any possible optimum area out of group boundaries.

Lastly, in case the new generated member of agent does not satisfy the inequality constraint shown in (6), it will be adjusted accordingly to maximum and minimum value of generation. For each group, the agent is ranked by its performance and greatest agent for each group is recorded as the new best group agent.

5.6. Update member of group depending on performance

The group with optimum value of best group agent compared with other groups adds one agent to its group and the worst value member of best group agent reduces one of its agent. From this process, the competitive group will grow its population to find more rich resources possible and the weakest group will decrease its member of agents.

If the weakest group member is left with only value of rate of death, d_{rate} its group will terminate and the best group will divide its population equally to form two new groups

5.7. Termination condition

This ELD optimization problem used a number of iteration, N_{iter} as a stopping criteria for the algorithm. When maximum iteration is reached, the COR algorithm stops the process and the best solution is recorded. Otherwise, the process repeats again from step 5.3.

6. Test system and configuration

For each test case, population size is set to 100 and 200 iterations have been conducted to compare solution quality with other methods using input data taken from [7]. The parameter setting for COR used for every case study is listed in Table 1.

Table 1: Parameter setting used for COR method

Parameter	Value
N_{group}	5
d_{rate}	3
D_{sch}	0.6
P_{sch}	0.9

The proposed COR optimization algorithm has been applied to solve ELD problem in 2 different test cases:

6.1. 6-unit test system

This case study consists of 6 generating units along with constraints of real power balanced, generating limits, ramp rate limits and prohibited operating zones. Transmission loss has been included in the problem. Total active power demand is 1263 MW. The obtained optimum results from COR are compared with results of other basic methods, such as PSO [7], GA [7] and NPSO-LRS [17].

6.2. 15-unit test system

It consists of large scale of 15 generating units with total active load demand of 2630 MW and taking into account the real power balanced with transmission losses, generating limits, ramp rate limits and prohibited operating zones constraints. The optimum results from COR are compared with other basic methods, such as PSO [7], GA [7], BFA [18] and ABC [19].

7. Results and discussion

All the simulations for ELD problem are implemented using MATLAB programming on PC specification with an Intel Core i7 Dual-core 2.80 GHz, 8 GB RAM. The simulation has been executed in many trials with desired parameter setting of COR algorithm until it obtained optimal result for performance analysis of the approach.

7.1. 6-unit test system

The optimum results obtained from 6 units test system using COR are compared with GA, PSO and NPSO-LRS in terms of total cost generation, tabulated in Table 2. The results show that COR method can produce slightly lower total generation cost compared with PSO and NPSO-LRS while GA is much higher. The power generator for each unit not trapped on their constraint unit area which are generating limit, prohibited operating zones and ramp rate limits as stated in [7]. The results of convergence characteristic of COR are shown in Figure 3. It shows that the COR has approached minimum global value and converged before reaching 160 iterations.

Table 2: Best solution for 6-unit test system

Power Generation (MW)	Optimization Method			
	GA	*PSO*	*NPSO-LRS*	***COR***
G_1	474.81	447.50	447.47	**448.00**
G_2	178.64	173.32	173.10	**173.07**
G_3	262.21	263.47	262.68	**264.63**
G_4	134.28	139.06	139.41	**138.44**
G_5	151.90	165.47	165.30	**165.40**
G_6	74.18	87.13	87.98	**86.41**
Total Power Generated (MW)	1,276.03	1,276.01	1,275.95	**1275.97**
Power Losses (Ploss)	13.02	12.96	12.95	**12.97**
Total Generation Cost ($/h)	15,459	15,450	15,450	**15449.92**

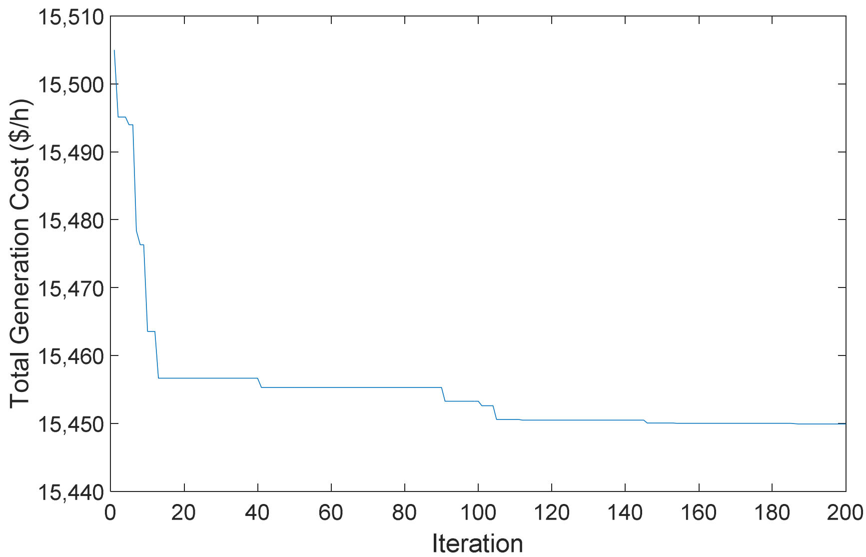

Figure 3 Convergence behavior of COR for 6-unit test systems

7.2. 15-unit test system

Table 3 presents the best solution of COR algorithm for 15 unit test system compared with GA, PSO, ABC and GA-API methods. As shown in Table 3, COR algorithm can achieve better quality solution than other methods with total generation cost of 32,717.07 $/h. The results obtained from proposed method comply with all constraints discussed in Section 3.3. Figure 4 provides the characteristic graph for convergence behavior between total cost generation and iteration. It noted that the COR algorithm drastically decreases until 20th iteration and slowly moved towards optimum result by the last iteration.

Table 3: Best solution for 15-unit test system

Power Generation (MW)	Optimization Method				
	GA	*PSO*	*ABC*	*GA-API*	***COR***
G_1	415.31	439.11	454.2778	454.70	**454.73**
G_2	359.72	407.97	369.7131	380.00	**379.30**
G_3	104.43	119.63	130.0000	130.00	**129.98**
G_4	74.99	129.99	124.3210	129.53	**129.78**
G_5	380.28	151.07	163.1341	170.00	**169.12**
G_6	426.79	460.00	460.0000	460.00	**459.97**
G_7	341.32	425.56	405.4317	429.71	**430.00**
G_8	124.79	98.57	85.6483	75.35	**103.79**
G_9	133.14	113.49	92.1289	34.96	**48.94**
G_{10}	89.26	101.11	157.4626	160.00	**133.79**
G_{11}	60.06	33.91	74.5293	79.75	**79.24**
G_{12}	50.00	79.96	79.8057	80.00	**79.80**
G_{13}	38.77	25.00	25.0000	34.21	**25.00**
G_{14}	41.94	41.41	19.3117	21.14	**18.24**
G_{15}	22.64	35.61	20.8153	21.02	**18.73**
Total Power Generated (MW)	2,668.4	2,662.40	2,661.58	2,660.36	**2,660.40**
Power Losses (Ploss)	38.28	32.43	31.58	30.36	**30.40**
Total Generation Cost ($/h)	33,113	32,858	32,787.84	32,732.95	**32,717.07**

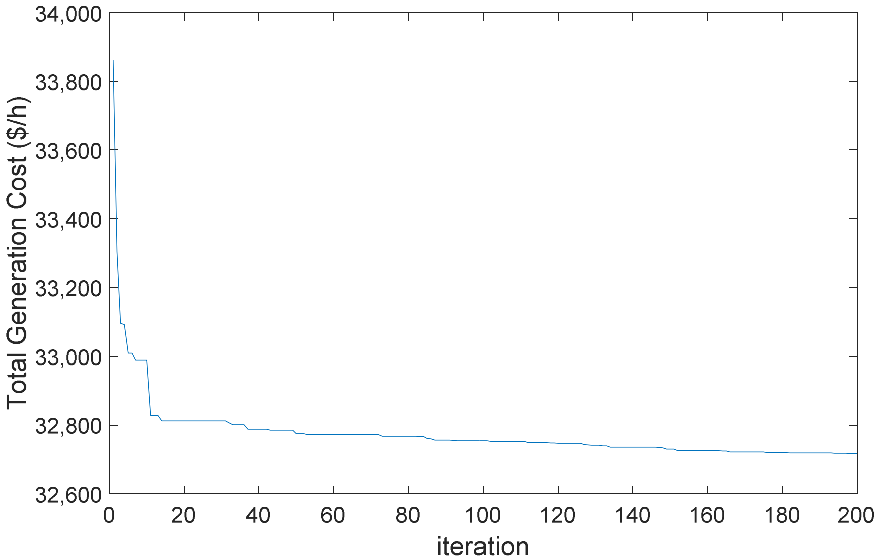

Figure 4 Convergence behavior of COR for 15-unit test systems

8. Conclusion

This paper has proposed a novel COR algorithm for solving two basic ELD problem test systems i.e. 6-unit and 15-unit test systems considering complex constraints including power balanced, generator limit, prohibited operation zones and ramp rate limits. The COR algorithm is tested for optimum solution and convergence behavior. It is proved that the proposed algorithm for non-convex ELD problems has the ability to achieve optimum solution over other basic heuristic optimization methods, such as GA, PSO, ABC, GA-API and NPSO-LRS.

Future studies will focus on enhancing of COR algorithm and apply to more complex problem of ELD test system with bigger network, then compare the performance with other advanced heuristic optimization methods.

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