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Thermal Unit Commitment Solution using Priority List Method and Genetic-Imperialist Competitive Algorithm

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Abstract

A novel strategy including a Priority List (PL) based method and a heuristic algorithm which is named Genetic-Imperialist Competitive Algorithm (GICA) has been proposed in this paper to solve thermal Unit Commitment Problem (UCP). This problem has been confined by some constraints like minimum down time, minimum up time, spinning reserve, load demand, and limited output power of the generating units. The optimization process is carried out in three steps. At first, a strategy based PL is used to find units priority, in second step the GICA employed to solve Economic Load Dispatch (ELD), and finally a correction strategy tried to find and replace better solutions. The accuracy and effectiveness of the proposed method is verified by two different case studies with 4 and 10 generation units system. The comparison of results with some other methods shows that proposed three step method has a better performance and achieve better solution in an admissible time interval.

Keywords: Economic load dispatch; Genetic-imperialist competitive algorithm; Priority list; Spinning reserve; Thermal unit commitment.

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1. Introduction

The UCP is an important economic scheduling problem in the electrical power systems. Considering the global industrialization, the electric power demand fluctuation is raising rapidly which results in different problems in the power system. One of these problems can be “how many and what generating units must be in line at any specific load to minimize the consuming fuel cost” that this problem is named UCP. As the electrical load demand changes periodically during specific time intervals, solving UCP would be a cyclic optimization process which is confined by some constraints. The unit Start-up Cost (SC) is another factor that should be aggregated to running cost of units [1].

The UCP can be divided in two sub-problems. First, scheduling OFF/ON status of units represented by 0/1 respectively. Next problem is ELD that reduces running cost in a specific hour or load. So UCP is a mixed-integer nonlinear problem. In last decades some methods have carried out to find better solutions. At first numerical and mathematical based methods were employed such as Priority List (PL) [2], dynamic programming [3], Lagrange relaxation [4], mixed integer linear programming [5]. These methods are based on some rules which result in exact response with good convergence rate. But their problem is big dimensional systems with many constraints. Recently heuristic methods such as Imperialist Competitive Algorithm (ICA) [6], Particle Swarm Optimization (PSO) [7], Lagrange Relaxation-PSO (LRPSO) [8,9], simulated annealing [10], artificial neural network [11], Genetic Algorithms (GA) [12,13,14,15], Evolutionary Programming (EP) [16], invasive weed optimization [17], Quantum-Inspired Evolutionary Algorithm (QIEA) [18], Binary/Real coded Artificial Bee Colony (BRABC)[19], Semi Definite Programming relaxation based technique combined with Selective Pruning (SDPSP) [20], and Quasi-Oppositional Teaching Learning Based algorithm (QOTLBO) [21] have been reported. Each algorithm has its own benefits and drawbacks, for instance PSO algorithm can be easily converged to optimum point well but its good response depends on initial population. The GA can recognize optimum solution area in its primary generations, however convergence rate isn’t fast enough and can’t result in very optimal solutions.

This paper has been organized as follows. In section two the UCP and ELD formulations and their related constraints are revealed. Developed PL method and GICA approach are demonstrated in section 3. Section 4 shows applying proposed method to UCP. The optimization results are shown for 4 and 10 generating units system in section 5 and finally section 6 reveals conclusions.

2. Problem formulation

The Objective of UCP is minimization the fuel cost of some generating units over a scheduling time period like 24 hours. The problem includes some constraint which can be formulated as below.

2.1. The UCP objective function

In UCP, the objective function can be expressed as follows:

$$TC = \sum_{t=1}^{T} \sum_{i=1}^{N} \{ F_i(P_{i,t})U_{i,t} + SC_i(1 - U_{i,t-1})U_{i,t} \} \tag{1}$$

as

$$F_i(P_i) = \sum_{i=1}^{N} a_i\,(P_i)^2 + b_i\,(P_i) + c_i \tag{2}$$

In this equations, TC is Total fuel Cost ($), N is number of generating units, T is total considered scheduling time (hours), P_i is output power of i_{th} unit (MW), F_i is Fuel cost of i_{th} unit ($), $P_{i,t}$ is out power of i_{th} unit at time t (MW). The a_i, b_i and c_i are fuel cost function coefficients of i_{th} unit, SC_i is startup cost of i_{th} unit ($), and $U_{i,t}$ is 0/1 status of i_{th} unit at time t.

2.2 Constraints

Due to some existing practical constraints on power systems, UCP is limited by some of them including power balance, spinning reserve, minimum up and down time and generated power limit.

2.2.1 Power balance

Sum of the output power of the in line generating units in a given time interval must supply the electrical load demand.

$$\sum_{i=1}^{N} U_{i,t}P_{i,t} = D_t \qquad t = 1, 2, \ldots, T \tag{3}$$

In this equation $U_{i,t}$ is on/off (1/0) status of i_{th} unit at time t, $P_{i,t}$ is output power of i_{th} unit at time t (MW), D_t is load demand at time t (MW).

2.2.2 Spinning reserve

The total maximum power of in line units must be more than load demand plus spinning reserve to maintain system reliability.

$$\sum_{i=1}^{N} U_{i,t}\,P_i^{max} \geq D_t + SP_t \qquad t = 1, 2, \ldots, T \tag{4}$$

In this equation, P_i^{max} is maximum output power of i_{th} unit and SP_t is spinning reserve at time t (MW).

2.2.3 Minimum up and down time

Minimum Up (*MU*) shows the number of hours that a unit must be ON constantly (H^{on}) before turning OFF and Maximum Down (*MD*) shows the number of hours that a unit must be OFF constantly (H^{off}) before turning ON.

$$H_{i,t}{}^{on} \geq MU_i \tag{5}$$

$$H_{i,t}{}^{off} \geq MD_i \tag{6}$$

In this equations, $H_{i,t}{}^{off}$ is number of hours which i_{th} unit is constantly OFF until time t (hours), $H_{i,t}{}^{on}$ is number of hours which i_{th} unit is constantly ON until time t (hours), MU_i is minimum up time of i_{th} unit (hours), and MD_i is minimum down time of i_{th} unit.

2.2.4 Generated power limits

It is clear that the generated power by a unit should be placed in its minimum and maximum borders.

$$P_i{}^{min}\, U_{i,t} \leq P_{i,t} \leq P_i{}^{max}\, U_{i,t} \tag{7}$$

In this equation, $P_i{}^{min}$ is minimum admissible output power of i_{th} unit, and $P_i{}^{max}$ is maximum admissible output power of i_{th} unit.

2.2.5 Ramp-rate constraints

Due to the this fact that generating power can't be raised or diminished by more than a certain amount from an hour to next one, the following equations can be added to the constraints, that means output power of unit *i* at time (hour) *t-1* until next time (*t*) can't be increased more than *RU* of that unit and output power of unit *i* at time *t* until next time (*t+1*) can't be reduced more than *RD* of that unit, which are formulated as below:

$$\begin{cases} P_{i,t} - P_{i,t-1} \leq RU_i \\ P_{i,t} - P_{i,t+1} \leq RD_i \end{cases} \tag{8}$$

In this equation, RU_i is ramp up amount of i_{th} unit, RD_i is ramp down amount of i_{th} unit.

3. The proposed method

This paper represents a strategy which is based on PL to solve UCP scheduling and uses GICA for solving ELD. Therefore an overview of PL, GA, ICA and proposed GICA have been demonstrated in details by this section.

3.1 The PL method

In PL method, units should be on line according to some of the defined characteristics of them, such as MD and maximum capacity so as to satisfy summation of the load demand and spinning reserve. The PL is a fast and simple method that is modified to find units scheduling in this paper.

3.2 Genetic algorithm

The GA is a heuristic method which is engendered on Darwinian's theory and is inspired from natural genetic. It involves some chromosomes that each feasible one of them can be a solution of the problem. Each chromosome includes some genes as the problem variables. The collection of these chromosomes are named population or generation which is evaluated by a fitness function that includes at least objective function of the problem. The best chromosomes are selected as elites. Thereafter crossover operator is applied to population that it means some chromosomes are selected as parents to produce their offspring (children) to new generation organization [12, 13]. Figure 1 shows a binary single point crossover that second half of both chromosomes has been changed.

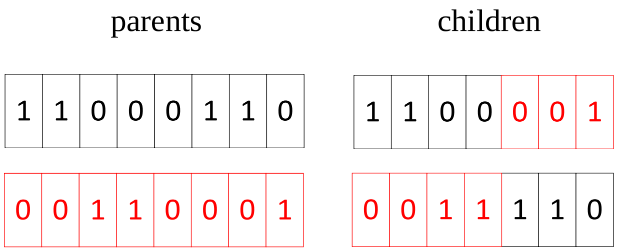


Figure 1: The binary GA Crossover

As the GA next operator after crossover, the mutation try to create some diversity in search space. It changes some of the genes values randomly. Figure 2 shows mutation operator in binary mode.

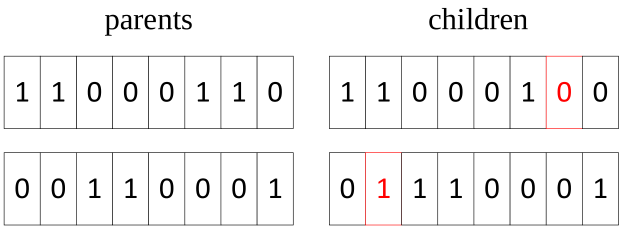


Figure 2: the Binary GA Mutation

The elitism operator pick best chromosomes or elites in every generation and don’t permit them to participate in crossover and mutation processes. If the stopping criteria satisfied, the best fitted chromosome is selected as GA final solution, otherwise the fitness function must be applied in recent generation again and the GA process would be repeated.

3.3 Imperialist competitive algorithm

The ICA [6] is a socio-politically search method. At first a set of randomly chosen countries are created then some of the best fitted countries are selected as imperialists and other countries are divided among them as their colonies in sort of the each imperialist’s power and accordingly initial empires would be constituted. The power of an empire equals to its relative imperialist power and a small amount of colonies mean power. Then each imperialist begins to assimilate its related colonies. It may occur a revolution in midway that means a colony changes its own situation by a stochastic manner. If a colony succeed to get better fitness value than its related imperialist, imperialist and colony positions would be exchanged. Then Imperialistic competition begins that weakest colony of weakest empire in every decade moves to another empire as new colony of it. If there is an empire without any colonies, this empire or imperialist can be collapsed or move to another empire as new colony of it. These rivalry would be stand firm until only one empire remains without any colonies. This alone imperialist is the ICA most powerful country and its final response. In some simulations, colonies are assimilated toward their own imperialists by an θ angle which it causes a deviation movement in search space and finding better solutions. But in this paper, as is shown in figure 3, the θ angle has been ignored. The figures 3 and 4 show the proposed assimilation and revolution in this paper.

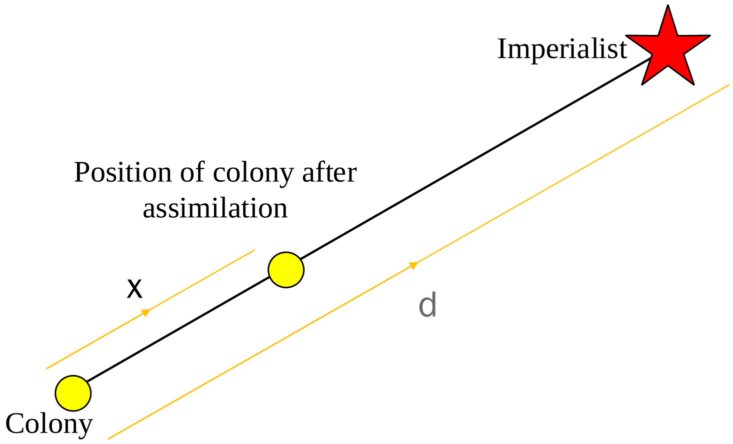


Figure 3: The proposed ICA Assimilation

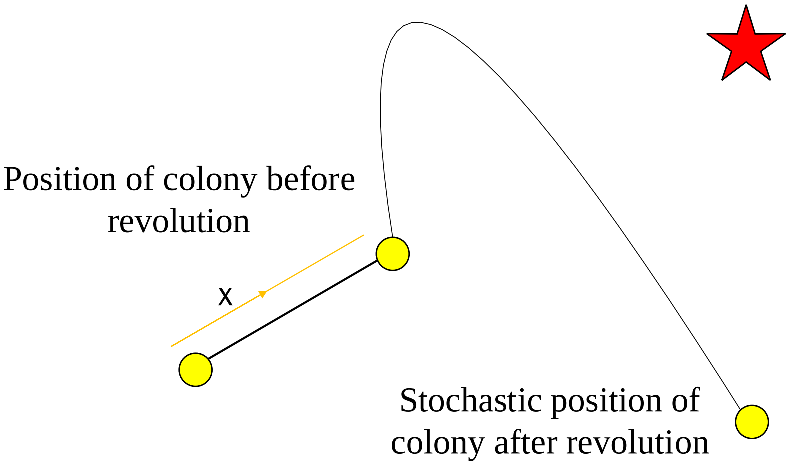


Figure 4: The proposed ICA Revolution

3.4 The genetic-imperialist competitive algorithm

The GICA is a heuristic method which has been proposed in this paper and is combination of genetic and imperialist competitive algorithms. Since GA can’t reach very optimum solutions, it has been selected as an optimum point range finder in order to give this address to ICA to find global optimum point. The GICA solves ELD and its effectiveness has been proved by three different case studies in 5th section. The flowchart of GICA has depicted in figure 5.

4. Appling the proposed method to UCP

This section represents how to exert the proposed strategy to solve thermal UCP and organized as follows. First a PL based method have been utilized for UCP scheduling then GICA solve ELD and finally an correction strategy tries to find better arrangements of units and replace them. With turning on of big units, a tremendous portion of load would be covered. The big units are ones with big capacity of electrical power. This units' MD and MU are big amounts and startup of them is more expensive, consequently they are proper for basic load feeding. These schedule may result in resemble units' characteristics so they must be analyzed more accurate. The equation (9) can be used for determining units' priority. The flowchart of proposed GICA for solving ELD has depicted in figure 5.

$$\textit{Units priority vector} = (P^{max}/\mathrm{Max}\,(P^{max})) + (MD/\mathrm{Max}\,(MD)) \qquad (9)$$

In this equation, P^{max} is units' maximum available power vector.

The proposed method have been demonstrated by three steps.

Step 1. Do PL. Calculate ON/OFF status of units in each hour according to the appendix that represented in rest of the paper.

Step 2.1. Solve ELD. Initialize GA population (chromosomes) randomly in defined range by relation (7) then the residual amount that is difference between available generated power and load demand is added to genes by a randomly way to satisfy relation (3). These method is a kind of constraint handling without using any penalty function. The selection operator would sort chromosomes according to their fitness value without elimination of them, thus all of them can be participated in mating pool as parents and create the their own offspring (children). Afterward, the best fitted chromosomes would be selected as elites, the crossover operator changes genes between two chromosomes (except elites) with the same locality, therefore relation (7) wouldn't be violated. Then if the best fitted chromosomes in this section were better than previous section elites, they would be replaced. The mutation operator changes genes randomly according to relation (7). If the best fitted chromosomes in this section are better than previous section's elites, they would be replaced again.

Step 2.2. Receive GA ultimate population which contains GA best solution and nominate them countries, then create some countries randomly in defined range by relation (7), thereupon aggregation of these countries would be ICA initial countries. Create empires and commence to assimilation and revolution colonies and permit to imperialist competition be formed between empires. To handle inequality constrains (relation (7)) after any assimilation, if P_i^m has violated, do as bellow:

$$Colony^m = [P_1{}^m, P_2{}^m, P_3{}^m, \dots, P_n{}^m]$$

$$If\ P_i{}^m > P_i{}^{max}$$

$$P_i{}^m = P_i{}^{max}$$

```
elseif $P_i^m < P_i^{min}$
$P_i^m = P_i^{min}$
end
```

In this equation, *n* is number of generating units, *m* is number of the imperialists and *i* is number of the violated unit.

Step 3. Apply corrections strategy. Search another ON/OFF conceivable scheduling in each time interval with turning off and on of units one by one without violating MD, MU and satisfying relation (4). Apply GICA to new schedules and replace the best solution in this phase if is better than ELD response gotten in previous step.

5. Simulation results

The proposed method are carried out for two case studies with 4, and 10 generation units system. The simulations have been executed by Matlab software.

- **Case study 1**

The first case study includes 4 generating units without considering spinning reserve during 8 hours and units' data have been given in table 1. The load demands for 8 hours are 450, 530, 600, 540, 400, 280, 290, and 500 respectively. The results have been depicted in table 2, then table 3 compares them with other methods.

Table 1: problem data for case study 1 [12]

	Unit 1	**Unit 2**	**Unit 3**	**Unit 4**
P_{max} (MW)	80	250	300	60
P_{min} (MW)	25	60	75	20
a ($/h)	213.00	585.62	684.74	252.00
b ($/MWh)	20.74	16.95	16.83	23.60
c ($/MW^{2}h)	0.0018	0.0042	0.0021	0.0034
Min up (h)	2	3	4	1
Min down (h)	4	5	5	1
Hot start cost ($/h)	150	170	500	0.00
Cold start cost ($/h)	350	400	1100	0.02
Cold start hours (h)	4	5	5	0
Initial status (h)	-5	8	8	-6

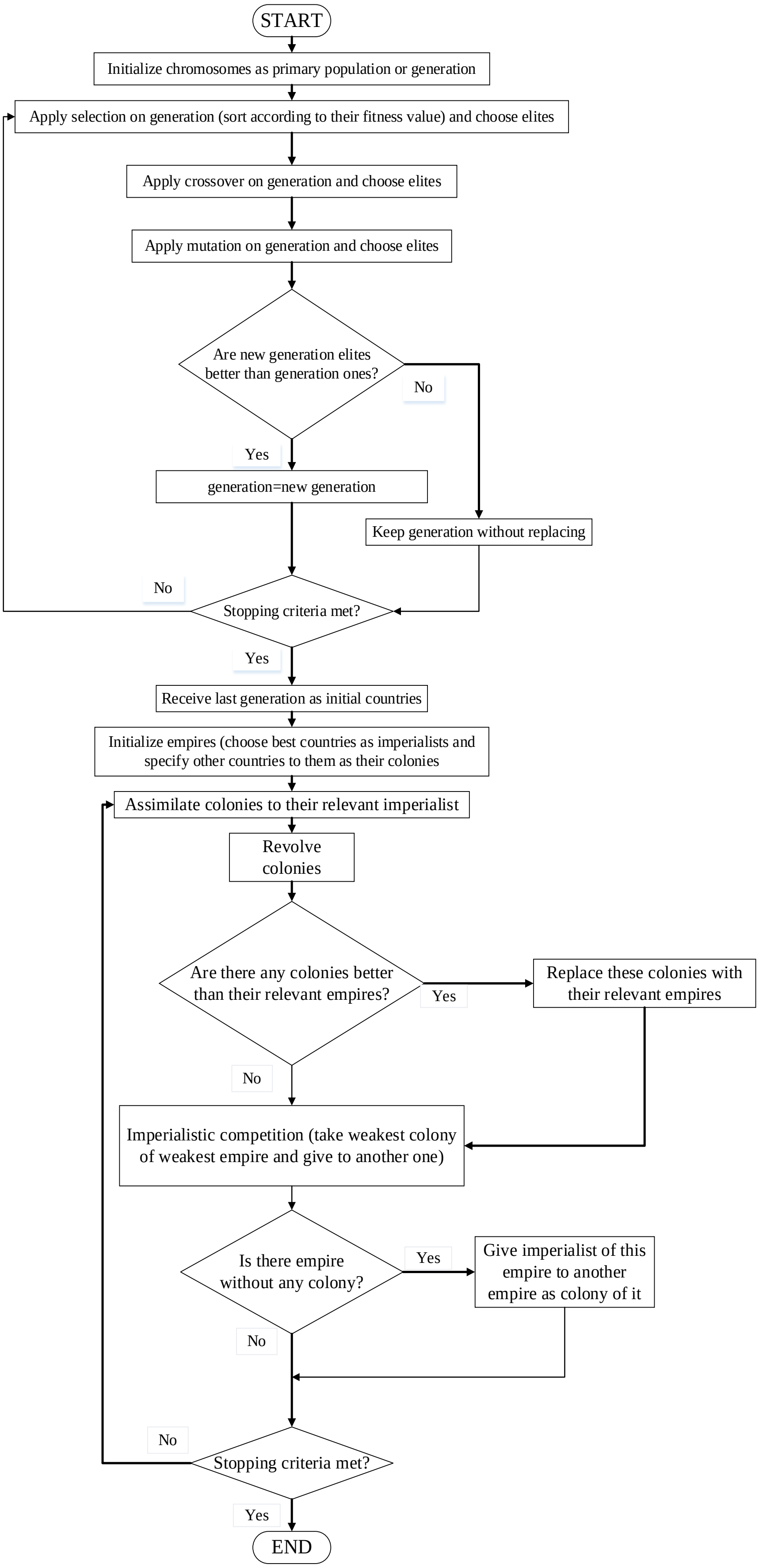
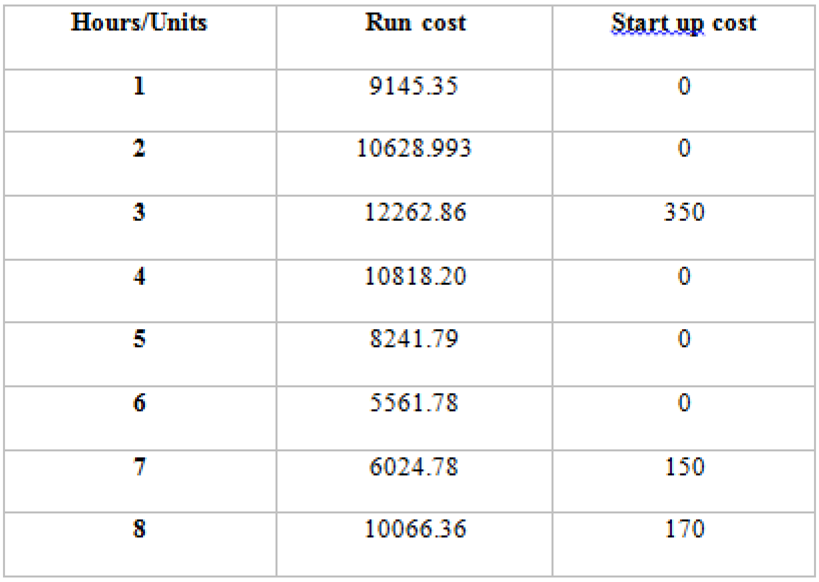


Figure 5: The proposed GICA flowchart

Table 2: Unit commitment results for case study 1



Hours/Units	Run cost	Start up cost
1	9145.35	0
2	10628.993	0
3	12262.86	350
4	10818.20	0
5	8241.79	0
6	5561.78	0
7	6024.78	150
8	10066.36	170

Total running cost=72750.12 $

Total startup cost=670 $

Total operational cost=73420.12 $

Table 3: The different algorithms results for case study 1

Algorithm	**Total running cost ($)**	**Number of generations**
DP [12]	74591.81	50
GA [12]	74336.54	50
Proposed method	72750.12	30

6. Conclusion

This paper has been represented a method for solving thermal UCP which uses a PL based method for units OFF/ON scheduling, then apply GICA for solving ELD. The proposed GICA doesn't use any penalty function for constraints handling and can escape local minimums well in order to give a near global response. At the end, a correction strategy searches other OFF/ON status of units in every hour and solve ELD for them one by one. The simulation has been carried out for two different case studies include 4, and 10 generation units system. The obtained results demonstrate the robustness and effectiveness of proposed method in solution quality during an acceptable consumption time in the face of some other methods in literature.

Table 4: problem data for case study 2 [8]

	Unit 1	**Unit 2**	**Unit 3**	**Unit 4**	**Unit 5**
P_{max} (MW)	455	455	130	130	162
P_{min} (MW)	150	150	20	20	25
a ($/h)	1000	970	700	680	450
b ($/MWh)	16.19	17.26	16.60	16.50	19.70
c ($/MW^{2}h)	0.00048	0.00031	0.002	0.00211	0.00398
Min up (h)	8	8	5	5	6
Min down (h)	8	8	5	5	6
Hot start cost($)	4500	5000	550	560	900
Cold start cost($)	9000	10000	1100	1120	1800
Cold start hours (h)	5	5	4	4	4
Initial status (h)	8	8	-5	-5	-6
	Unit 6	**Unit 7**	**Unit 8**	**Unit 9**	**Unit 10**
P_{max} (MW)	80	85	55	55	55
P_{min} (MW)	20	25	10	10	10
a ($/h)	370	480	660	665	670
b ($/MWh)	22.26	27.74	25.92	27.27	27.79
c ($/MW^{2}h)	0.00712	0.00079	0.00413	0.00222	0.00173
Min up (h)	3	3	1	1	1
Min down (h)	3	3	1	1	1
Hot start cost ($)	170	260	30	30	30
Cold start cost ($)	340	520	60	60	60
Cold start hours (h)	2	2	0	0	0
Initial status (h)	-3	-3	-1	-1	-1

Table 5: Unit commitment results for case study 2

Hours/Units	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Run cost**	**Start up cost**
1	455	245	0	0	0	0	0	0	0	0	13683.1297	0
2	455	295	0	0	0	0	0	0	0	0	14554.4997	0
3	455	370	0	0	25	0	0	0	0	0	16809.4485	900
4	455	455	0	0	40	0	0	0	0	0	18597.6677	0
5	455	390	0	130	25	0	0	0	0	0	20020.0195	560
6	455	360	130	130	25	0	0	0	0	0	22387.0445	1100
7	455	410	130	130	25	0	0	0	0	0	23261.9795	0
8	455	455	130	130	30	0	0	0	0	0	24150.3407	0

9	455	455	130	130	85	20	0	0	0	0	27251.0560	860
10	455	455	130	130	162	33	25	10	0	0	30057.5503	60
11	455	455	130	130	162	73	25	10	10	0	31916.0611	60
12	455	455	130	130	162	80	25	43	10	10	33890.1629	60
13	455	455	130	130	162	33	25	10	0	0	30057.5503	0
14	455	455	130	130	85	20	25	0	0	0	27251.0560	0
15	455	455	130	130	30	0	0	0	0	0	24150.3407	0
16	455	310	130	130	25	0	0	0	0	0	21513.6595	0
17	455	260	130	130	25	0	0	0	0	0	20641.8245	0
18	455	360	130	130	25	0	0	0	0	0	22387.0445	0
19	455	455	130	130	30	0	0	0	0	0	24150.3407	0
20	455	455	130	130	162	33	25	10	0	0	30057.5503	490
21	455	455	130	130	85	20	25	0	0	0	27251.0560	0
22	455	455	0	0	145	20	25	0	0	0	22735.5210	0
23	455	425	0	0	0	20	0	0	0	0	17645.3637	0
24	455	345	0	0	0	0	0	0	0	0	15427.3404	0

Total running cost=559847.6081 $

Total startup cost=4090 $

Total operational cost=563937.6081 $

Table 6: The different algorithms results for case study 2

Algorithm	**Total operational cost ($)**	**Average time (sec)**
ICA [6]	563,938	48
LRPSO [8]	565,870	NA
ELRPSO [9]	563,938	2.46
PSGA [13]	591,715	677
UCGA [14]	563,977	85
DACGA [15]	563,987	NA
EP [16]	564,551	100
QIEA [18]	563,938	7.6
BRABC [19]	563,937.72	40.75
SDPSP [20]	563,977	NA
QOTLBO [21]	563,937.69	2.76
Proposed method	563,937.60	8.89

7. Recommendations

Due to the some problems related to using fossil fuel sources in thermal power plants such as sources terminating, environmental pollution, and high costs, the recommendations are as below:

i. The proposed PL method can be used as a fast and effective procedure for units' priority determination in each hour for UCP problem.
ii. The novel HGICA is an exact method for fuel cost reduction that should be used for solving ELD.

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Appendix

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for all times
  for all units (with Eq. (9) order)
    if H_(i,t) is positive and equal or less than MU
      Turn on unit
    end
    if Eq. (3) hasn’t been satisfied
      if H_(i,t) is bigger than MU
        Turn on unit
      end
    end
    if Eq. (4) hasn’t been satisfied
      if H_(i,t) is equal or less than –MD
        Turn on unit
      end
    end
  for all units (with eq.(9) Reverse order)
    if or(Unit turned off , Demand decreased)
```

```
if H_(i,t-1) is bigger that MU
if Eq. (4) satisfied and or(2'nd Peak Load Time-Time>MD , Time>2'nd Peak Load Time)
Turn off unit
else
Turn on unit
end
elseif (H_(i,t) is less than –MD)
if Eq. (4) hasn't been satisfied
Turn off unit
else
Turn on unit
end
elseif (H_(i,t) is negative)
Turn off unit
end
end
for all units (with Eq. (9) order)
if Eq. (4) hasn't been satisfied
Turn on unit
end
end
end
```

```
end
end
```

where H_(i,t) is number (positive or negative) of hours which unit i have been constantly ON or OFF until time t.