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Economic Load Dispatch with Considering the Valve-Point Effects and Ramp Rate Limits of Generators Using Evolutionary Algorithms

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Abstract

Nowadays, economic load dispatch between generation units with least cost involved is one of the most important issues in utilizing power systems. In this paper, a new method i.e. Water Cycle Algorithm (WCA) which is similar to other intelligent algorithm and is based on swarm, is employed in order to solve the economic load dispatch problem between power plants. WCA is used to solve the complicated problems including non-linear cost functions such as the constraint for input steam valve, constraint for loss, ramp rate of generators and prohibited operating zones of generators' production. This algorithm is employed on a system with 3 units and load demand of 850 MW and on a system with 15 units and load demand of 2630 MW with and without considering the constraints. The results of the paper comparing to the results of the other valid papers show that the proposed algorithm can be used to solve any kind of economic dispatch problems with proper results.

Keywords: *Economic load dispatch, water cycle algorithm, valve- point effect*

1. Introduction

The aim of economic load dispatch (ELD) is to optimally dispatch the demanded load of the power system between generation units that are online. Optimal or economic load dispatch is the allocation of generation between active units in a way by simultaneous supplying the load demand, production range, increasing or decreasing rates of units, prohibited operating zones and other constraints of power plants are considered and by considering the loss of transmission network, the overall cost of production can be minimized in any time period and for forecasted load condition.

Different methods with the aim of achieving to the optimal solution are presented in economic load dispatch problem. Generally, these methods can be classified into three groups: 1- analytical methods 2- programmable methods and 3- intelligent methods.

Analytical methods that are based on mathematical optimization methods have some advantages such as having too many ways of proving and obtaining to a mathematical optimum solution. However, these methods have problems finding the optimum point when the objective function is non-linear or non-derivable [1]. Programmable methods are like dynamic programming method [2-3] and can some certain parts of economic load dispatch problems because they do not need derivation but they would not solve problems with high dimensions or they need plenty of time to obtain the answer. Real ELD problem considering equivalent and in-equivalent constraints such as ramp rate of generators, valve-point effects in generation units and etc. would take the form of a non-smooth optimization problem. Therefore, finding the global optimum for this problem is not simply possible using classic methods, so evolutionary algorithms are proposed to overcome these obstacles.

"In this paper, a novel method is used in order to solve the economic load dispatch problem between power plants. Problem constrains are considered including the constraint for input steam valve, constraint for loss, ramp rate of generators and prohibited operating zones of generators' production."

2. Economic Load Dispatch Problem

As mentioned before, ELD is defined as a process of allocating the levels of generation for each power plant in combinatorial form in a way the demand of system is supplied completely and economically [4].

In order to reach to the optimal production for each power plant, curve of fuel cost has to be modeled as a mathematical relation. In classic case, this function is modeled as quadratic function (Figure 1) but in practical and developed cases; this model is modeled as non-linear and discontinues form due to several constraints.

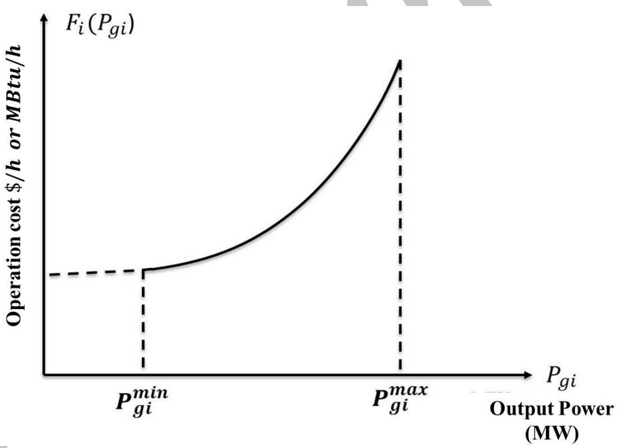

Figure 1. The curve of fuel cost for generators in smooth and continues condition

The first relation in optimal load dispatch problem is the law of conservation of energy. The sum of generated power by power plants has to be equal to the load demanded from grid.

$$\sum_{i=1}^{ng} P_{gi} = P_D \qquad (1)$$

Where P_D is the demand power, P_{gi} power generated (output power) by i_{th} generator, ng number of generators in the system.

In more complex load dispatch problems, the loss of transmission network (P_L) has to be added to the equation (1).

$$\sum_{i=1}^{ng} P_{gi} = P_D + P_L \tag{2}$$

Equation (2) expresses that the sum of generated power is equal to sum of the consuming power including power consumed in loads and power wasted in transmission line. This equation is a form of the law of conservation of energy. The value of P_L is calculated by equation (3).

$$P_L = \sum_{i=1}^{ng}\sum_{j=1}^{ng} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{ng} B_{0i} P_{gi} + B_{00} \tag{3}$$

Where B_{ij}, B_{0i} and B_{00} are factors of loss function for transmission network.

Fuel cost of each power plant is calculated from the following relation.

$$F\left(P_{gi}\right) = a_i P_{gi}^2 + b_i P_{gi} + c_i \tag{4}$$

Where F is fuel cost and c_i, b_i, a_i are factors for fuel cost function of i_{th} unit.

In Figure 1, P_{gi}^{min} is the minimum loading range that below this range it would not be economical (or technically impossible) for the unit and P_{gi}^{max} is output maximum range for unit. Therefore, output power of generator has to be within minimum and maximum ranges.

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \tag{5}$$

In steam plants, several steam valves are used in turbine for controlling the output power of the generators. Opening the valve-point effects would lead to a sudden increase in loss and causes ripples in input-output curve and consequently causes cost function non-smooth. If the valve-point effect is considered in power plants, cost function of their generation would take a non-smooth form due to related mechanical effects.

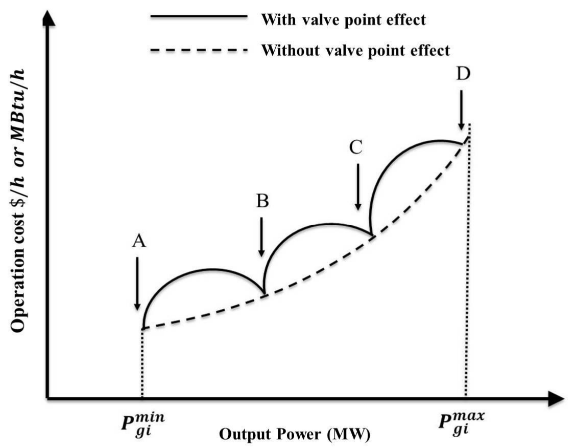

Figure 2. Fuel cost curve for generators with 4 steam valves

This influence is usually modeled by adding a sinusoidal term in cost function of power plants. Therefore, equation (4) considering the effect of input valve-point is expressed as equation (6) [5].

$$F_i\left(P_{gi}\right) = a_i P_{gi}^2 + b_i P_{gi} + c_i + \left| e_{gi} \times Sin\left(f_{gi} \times \left(P_{gi}^{\min} - P_{gi} \right)\right)\right| \tag{6}$$

where e_{gi} and f_{gi} are factors for the valve-point effects on i_{th} generator.

2-1 Limitation of ramp rate of generators

In practice, steam plants do not have the ability to increase or decrease their power suddenly due to thermo-dynamical and mechanical limitations of boilers and turbines, so the increase and decrease has to be with a certain rate [6].
If an increase in power is required:

$$P_i\left(t\right) - P_i\left(t-1\right) \le UR_i \tag{7}$$

If a decrease in power is required:

$$P_i\left(t-1\right) - P_i\left(t\right) \le DR_i \tag{8}$$

where UR_i and DR_i are up and down range of i_{th} generator and $P_i(t-1)$ generating power of i_{th} unit in previous hour.

2-2 Prohibited Operating Zones

Fuel cost curve would sometimes have some discontinuous points. There are some reasons for this such as valve-point effects performance, sudden vibrations on shafts and physical limitations in devices [7]. These discontinuous points are considered in fuel cost curve as a constraint of equation (9) in the ELD problem [8].

$$P_{gi} \in \begin{cases} P_{gi}^{\min} \le P_{gi} \le P_{gi}^{l} \\ P_{gi,j-1}^{u} \le P_{gi} \le P_{gi,j}^{l}, \; j = 2,3,\ldots, pz_i \\ P_{gi,pz_i}^{u} \le P_{gi} \le P_{gi}^{\max} \end{cases} \tag{9}$$

3. Water Cycle Algorithm

In this section, a new algorithm inspired by water cycle in nature is presented which is not employed for optimization on any power systems [9]. Similar to other heuristic swarm algorithms, the proposed method is started with an initial population named rain drops (N_{pop}). A matrix is produced as rain drops with a dimension of N_{pop}*N_{var} for initializing the optimization. Rows and columns of this matrix are composed of population (N_{pop}) and number of design variables (N_{var}) or generation units, respectively.

$$\text{Population of raindrops} = \begin{bmatrix} Raindrop_1 \\ Raindrop_2 \\ Raindrop_3 \\ \vdots \\ Raindrop_{N_{pop}} \end{bmatrix} = \begin{bmatrix} X_1^1 & X_2^1 & X_3^1 & \dots & X_{N_{var}}^1 \\ X_1^2 & X_2^2 & X_3^2 & \dots & X_{N_{var}}^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_1^{N_{pop}} & X_2^{N_{pop}} & X_3^{N_{pop}} & \dots & X_{N_{var}}^{N_{pop}} \end{bmatrix} \quad (10)$$

In a random matrix with certain dimension, the values of every variable $X_1, X_2, X_3, \dots, X_N$ can be real or complex. Cost function or cost of the problem is defined as below:

$$C_i = Cost_i = f(X_1^i, X_2^i, \dots, X_{N_{var}}^i), \ i = 1,2,3,\dots,N_{pop} \quad (11)$$

After producing the initial matrix, N_{SR} number of them is considered as sea and rivers. Besides, a drop with the best answer is chosen as sea. The other members as rain drops would flow to the rivers or directly to the sea. In fact, N_{SR} is the sum of river (user parameter) and sea.

$$N_{SR} = Number\ of\ Rivers + \underbrace{1}_{Sea} \quad (12)$$

It would be understood which drop will go to which river based on the stream intensity of each river:

$$NS_N = round\left\{\left|\frac{Cost_n}{\sum_{i=1}^{N_{sr}} Cost_i}\right| \times N_{Raindrops}\right\}, n = 1,2,\dots,N_{SR} \quad (13)$$

After flowing the drop to the river, it has to be known that how rivers are flown down to seas. Movement of each stream to a river is known by a line that joins them. This distance is calculated randomly.

$$X \in (o, \mathrm{C} \times d)\ ,\ \mathrm{C} > 1 \quad (14)$$

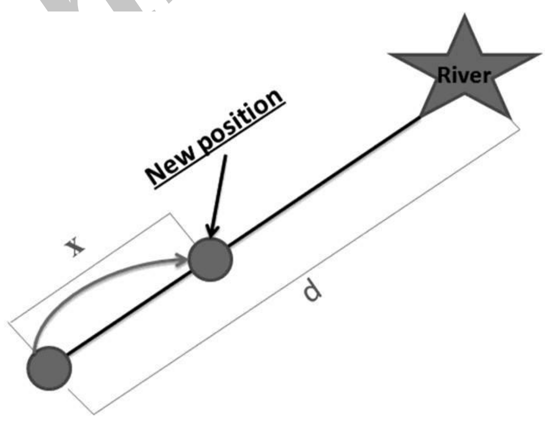

Figure 3. Schematic of flowing a stream to a river

Where C is a value between 1 and 2 (near to 2). The current distance between stream and river is shown by parameter d. X in equation (14) is a random value between 0 and C*d. The values of C greater than 1 enables stream to flow to the river in different directions. Therefore, the best value for C would be 2. This concept can be used in flowing rivers to the sea. Hence, new positions for stream and river can be defined as follow [10].

$$X_{Stream}^{i+1} = X_{Stream}^{i} + rand \times C \times \left(X_{River}^{i} - X_{Stream}^{i}\right) \quad (15)$$

$$X_{River}^{i+1} = X_{River}^{i} + rand \times C \times \left(X_{Sea}^{i} - X_{River}^{i}\right) \quad (16)$$

Where rand is a random number with uniform distribution between 0 and 1. After updating the position of each drop and investigating the objective function, if the proposed solution by stream is better than a river connected to it, position of stream and river are changed (i.e. stream would be river and vice versa). This displacement could be happened for river and sea.
The evaporation criterion is investigated after the abovementioned stages. When the position of a stream or river is completely corresponding with the position of a sea, it means that it has flown to sea. In this condition, evaporation is done and new streams and drops are again flown to the mountains by rain and the above procedure is repeated.

$$if \quad \left|X_{Sea}^{i} - X_{River}^{i}\right| < d_{max} \;,\; i = 1,2,3,\dots,N_{sr} - 1 \quad (17)$$

Evaporation and raining process
end
where d_{max} is a small number near to zero and controls the depths of search close to sea. Greater values of d_{max} increase the search space and small values if depth. d_{max} is decreased in any repetition.

$$d_{max}^{i+1} = d_{max}^{i} - \frac{d_{max}^{i}}{max\,iteration} \quad (18)$$

If the above condition is set, rain will come and all the above procedure would be repeated. Equation (19) is used for specifying the new position of newly produced streams.

$$X_{Stream}^{new} = LB + rand \times (UB - LB) \quad (19)$$

where LB and UB are the lower and upper range of the problem, respectively.
Besides, there may be some streams that would flow directly to the sea without flowing to a river.

$$X_{Stream}^{new} = X_{Sea} + \sqrt{\mu} \times randn(1, N_{var}) \quad (20)$$

where μ is the search domain near to sea. randn is a random number of normal distribution. Great values for μ increase the possibility of going out of the possible area. Besides, small values for μ causes the algorithm to search in a smaller area near to sea. The best value for μ is selected 0.1.
Stop criterion in heuristic algorithm is usually the best calculated answer in which stop criterion would be defined as maximum number of iteration, processing time or ε a non-negative small value as tolerance between two previous results. Performance of WCA is agreeable to maximum iteration as a convergence criterion.

4. Application of WCA on ELD problem

In this paper, a new algorithm called Water Cycle is used to optimize the overall fuel cost of power plants. At first, the initial values of WCA like N_{pop}, N_{sr} and data related to generation units such as factors of fuel cost function of generators, output limitations of generators and the demanded load are summoned by the system. After this, population

matrix of drops is produced in a random manner. At third stage, constraints of the ELD problem are investigated.
In order to investigate the power balance condition, the value of $\emptyset$ is calculated for each population like according to the following equation:

$$\emptyset = (P_D + P_L) - \sum_{i=1}^{ng} P_{gi} \tag{21}$$

If $\emptyset$=0, it means that the inequality constraint is met; otherwise, the calculated $\emptyset$ is added to a unit randomly. Inequality constraint is then checked for that unit. If the power is more than maximum power of that unit, power is set to the maximum value. Since $\emptyset$ can also be negative, so if the power is less than the minimum power of that unit, then the power is set to minimum value. Therefore, we have:

$$P_{gi} = \begin{cases} P_{gi}^{max} & if \quad P_{gi} > P_{gi}^{max} \\ P_{gi}^{min} & if \quad P_{gi} < P_{gi}^{min} \end{cases} \tag{22}$$

Now we go back to the second stage and repeat it until $\emptyset = 0$.
At fourth stage, cost of one drop and at fifth stage the intensity of stream for river and sea re calculated. At sixth stage, flowing the streams to the rivers and rivers to the seas are investigated. After updating the position of each drop and investigating the objective function, if the proposed solution by a stream is better than a river connected to it, position of stream and river are changed (seventh stage). This stage could be happened for river and sea (eighth stage). Evaporation condition which has an important role in preventing the algorithm to be trapped in the local minima is investigated. At next stage, d_{max} is reduced. When the distance between river and sea is less than d_{max}, it means that river has reached to the sea. In other words, if the evaporation condition is met, rain will occur based on equations (19) and (20). And finally stop criterion is checked. Performance of WCA is usually agreeable to maximum iteration as a convergence criterion. If the stop criterion is met, algorithm will stop; otherwise it goes back to the third stage.

5. Simulation

In order to investigate the effectiveness of WCA, different sample systems are tested for solving the ELD problem considering the effect of steam valve, ramp rate limitation and prohibited operating zones constraint.

5-1- System with 3 units

This sample system is composed of 3 generation units with quadratic fuel cost function in which the valve-point effects is considered. Table 1 gives the data of upper and lower ranges of each generation units and factors of fuel cost function (a, b, c, e, f) for these three units considering the valve-point effects and total demand of 850 MW.

Table 1. Comparison of the best, worst and the medium results for 50 times execution of WCA with other algorithm. In this system, parameters of WCA are as follow:

Unit No	Minimum cost ($)	Average cost ($)	Maximum cost ($)
1	300.26689	300.26686	300.26708
2	149.73310	149.73313	149.73310
3	400	400	399.99980
$\sum \boldsymbol{P_i}$ (MW)	850	850	850
$\boldsymbol{F_{Total}}$ ($/h)	8234.07174	8234.07175	8234.07176

Table 2. Unit data for the 3-unit test system

Unit No	P_i^{min} (MW)	P_i^{max} (MW)	*a* ($/MW^2)	*b* ($/MW)	*c* ($)	e	f
1	100	600	0.001562	7.92	561	300	0.0315
2	50	200	0.004820	7.97	78	150	0.0630
3	100	400	0.001940	7.85	310	200	0.0420

$N_{pop} = 40\ , N_{sr} = 10\ , d_{max} = 0{,}1$

Table 3. Comparison of the results of system with 3 units

Method	Minimum cost ($)	Average cost ($)	Maximum cost ($)	Mean simulation time (min)
GA[11]	8234.4190	8287.4835	8234.0206	35.80
EP[11]	8234.4190	8249.4092	8289.6812	6.78
SA[11]	8234.1355	8252.7256	8286.6719	-
NSS[11]	8234.0756	8234.0756	8234.0756	-
GAB[12]	8234.08	-	-	32.46
MFEP[12]	8234.08	8234.71	8241.8	8.00
FA[13]	8234.074	8234.08	8241.23	-
PSO-SQP[14]	8234.1	8234.1	-	3.37
CPSO[15]	8234.07	-	-	2.25
CPSO-SQP[15]	8234.07	-	-	2.06
SDE[16]	8234.0717	-	-	-
GA–PS–SQP[17]	8234.1	8234.1	-	15.28
CASO[18]	8234.07	-	-	-
FCASO-SQP[18]	8234.07	-	-	-
GSA[19]	8234.07	8234.11	8241.95	-
BFOA[20]	8234.1	-	-	-
FA[20]	8234.4	-	-	-
WCA	8234.07174	8234.07175	8234.07176	0.81

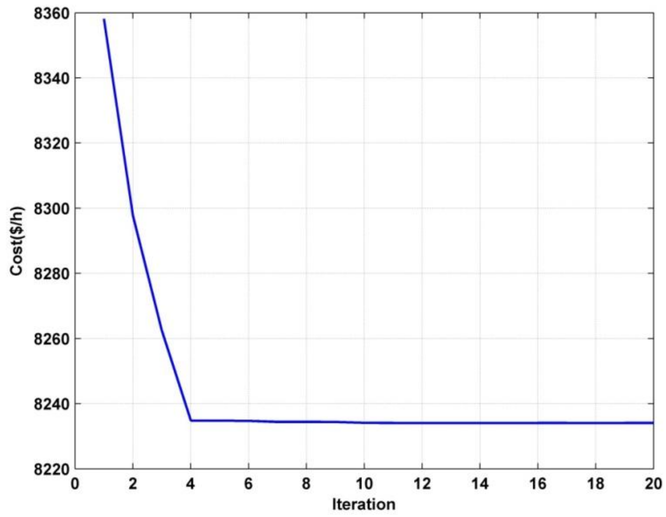

Figure 4. Convergence diagram of WCA for system with 3 units considering the valve-point effects and demand of 850 MW

5-2- System with 15 units

The second system under study has 15 generators and a total load demand of 2630 MW. Data of this system including upper and lower ranges of each generation units, factors of fuel cost function (a, b, c) for these three units, data of prohibited operating zones and network loss matrix is given in ref [21]. Since there is no total accordance between literatures and for a more accurate comparison, at first 30 executions are performed considering ramp rate and then 30 executions are done without this constraint. Parameters of algorithm are set as follow:

$N_{pop} = 120 \, , N_{sr} =$

Figures 5 and 6 and Tables 3, 4 and 5 show the convergence diagram, optimal solutions in 30 executions and comparison with other methods with and without considering the ramp rate constraint, respectively.

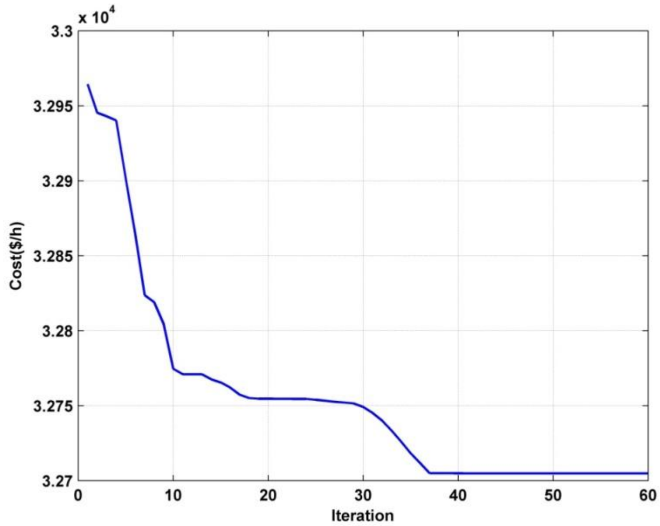

Figure 5. Convergence diagram of WCA for system with 15 units considering ramp rate

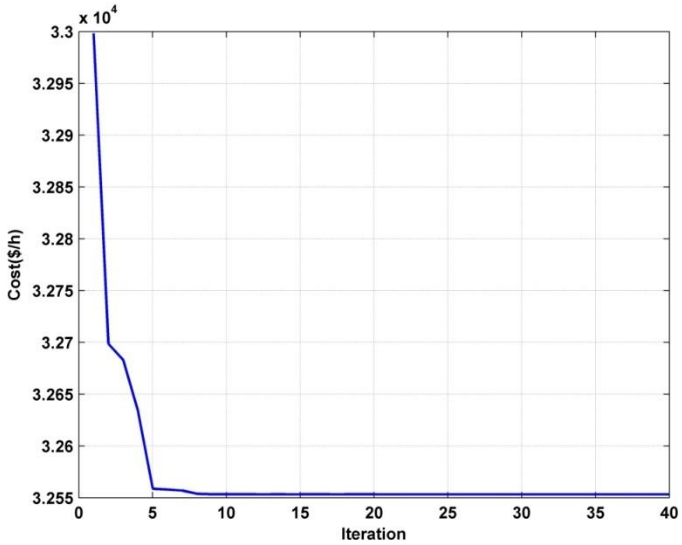

Figure 6. Convergence diagram of WCA for system with 15 units without considering ramp rate and load of 2630 MW

Table 4. Results of WCA for system with 15 units and load of 2630 MW

Unit No	With ramp rate limits			Without ramp rate limits		
	Minimum cost ($)	Average cost ($)	Maximum cost ($)	Minimum cost ($)	Average cost ($)	Maximum cost ($)
P_1 (MW)	455	455	455	455	455	455
P_2 (MW)	380	380	380	455	455	455
P_3 (MW)	130	130	130	130	130	130
P_4 (MW)	130	130	130	130	130	130
P_5 (MW)	170	170	170	231.8200	231.8200	231.81098
P_6 (MW)	460	460	460	460	460	460
P_7 (MW)	430	430	430	465	465	465
P_8 (MW)	71.76248	71.76248	60	60	60	60
P_9 (MW)	58.89902	58.89902	70.63822	25	25	25
P_{10} (MW)	160	160	159.99417	30.46537	30.46537	30.47065
P_{11} (MW)	80	80	80	79.996484	79.996484	79.996484
P_{12} (MW)	80	80	80	80	80	80
P_{13} (MW)	25	25	25	25	25	25
P_{14} (MW)	15	15	15	15	15	15
P_{15} (MW)	15	15	15	15	15	15
$\sum P_i$ (MW)	2660.6614	2660.6614	2660.6614	2657.28186	2657.28186	2657.28186
F_{total} ($/h)	32704.45005	32704.45005	32704.82844	32553.36664	32553.36664	32553.36678

Table 5. Comparison the results of WCA with different methods for system with 15 units considering ramp rate and load of 2630 MW

Unit No	GAAPI [22]	MPSO [23]	APSO [24]	SPSO [25]	PC_PSO [25]	SOH_PSO [25]	DSPSO–TSA [26]	SSGA [27]	θ-PSO [28]	SWT_PSO [29]	MDE [30]	IPSO [31]	GA [32]	WCA
P_1 (MW)	454.7	455.0000	455.00	455	455	455	453.627	455.000	445	445	454.99	445	415.31	455
P_2 (MW)	380.0000	380.0000	380.01004	380	380	380	379.895	380.000	380	380	379.99	380	359.72	380
P_3 (MW)	130.0000	130.0000	130.00	130	130	130	129.482	130.000	130	130	130	130	104.42	130
P_4 (MW)	129.53	130.0000	126.52284	129.28	127.15	130	129.923	130.000	130	130	129.99	130	74.98	130
P_5 (MW)	170	170.0000	170.01312	164.77	169.91	170	168.956	170.000	170	170	169.99	170	380.28	170
P_6 (MW)	460.0	460.0000	460.00	460	460	459.96	459.907	460.000	460	460	459.99	460	426.79	460
P_7 (MW)	429.71	430.0000	428.28356	424.52	430	430	429.971	430.000	430	430	429.99	430	341.31	430
P_8 (MW)	75.35	92.7278	60.00	60	108.38	117.53	103.673	106.25	71.8045	71.74	60	71.8762	124.78	71.76248
P_9 (MW)	34.96	43.0282	25.00	25	77.41	77.90	34.909	25.00	60.2379	58.92	70.41	58.98125	133.14	58.89902
P_{10} (MW)	160.00	140.1938	159.78932	160	97.76	119.54	154.593	160.00	158.7524	160	159.99	160	89.25	160
P_{11} (MW)	79.75	80.0000	80.00	80	67.61	54.50	79.559	80.00	80	80	79.99	80	60.5	80
P_{12} (MW)	80.00	80.0000	80.00	72.62	73.26	80	79.388	80.00	80	80	79.99	80	49.99	80
P_{13} (MW)	34.21	27.6403	33.70376	25	25.57	25	25.487	25.00	25.0078	25	25	25	38.77	25
P_{14} (MW)	21.14	20.7610	55.00	44.83	19.57	17.86	15.952	15	15.0147	15	15.07	15	41.94	15
P_{15} (MW)	21.02	22.2724	15.00	49.42	38.93	15	15.640	15	15.0040	15	15.16	15	22.64	15
$\sum P_i$ (MW)	2660.36	2661.6235	2658.3226	2660.44	2660.55	2662.29	2660.96	2661.3	2660.821	2660.66	2660.55	2660.8575	2666.93	2660.661
F_{total} ($/h)	32732.95	32738.417	32742.7774	32798.69	32775.36	32751.39	32715.06	32711	32706.5504	32704.45	32704.9	32706.6580	33113	32704.450

Table 6. Comparison the results of WCA with different methods for system with 15 units without considering ramp rate and load of 2630 MW

Generator No	PSO[33]	CPSO[34]	CPSO2[34]	AIS[35]	DE[36]	WCA
P_1 (MW)	439.1162	450.05	450.02	441.1587	454.997	455
P_2 (MW)	407.9727	454.04	454.06	409.5873	419.997	455
P_3 (MW)	119.6324	124.82	124.81	117.2983	129.997	130
P_4 (MW)	129.9925	124.82	124.81	131.2577	129.998	130
P_5 (MW)	151.0681	151.03	151.06	151.0108	269.917	231.8200
P_6 (MW)	459.9987	460	460	466.2579	459.990	460
P_7 (MW)	425.5601	434.53	434.57	423.3678	429.995	465
P_8 (MW)	98.5699	148.41	148.46	99.948	60.007	60
P_9 (MW)	113.4936	63.61	63.59	110.684	25.001	25
P_{10} (MW)	101.1142	101.13	101.12	100.2286	63.111	30.46537
P_{11} (MW)	33.9116	28.656	28.655	32.0573	79.973	79.996484
P_{12} (MW)	79.9583	20.912	20.914	78.8147	79.983	80
P_{13} (MW)	25.0042	25.001	25.002	23.5683	25.001	25
P_{14} (MW)	41.4140	54.418	54.414	40.2581	15.001	15
P_{15} (MW)	35.6140	20.625	20.624	36.9061	15.000	15
$\sum \boldsymbol{P_i}$ (MW)	2662.4	2662.1	2662.1	2662.04	2657.966	2657.28186
$\mathbf{F_{total}}$ ($/h)	32858	32835	32834	32854	32588.865	32553.36664

5-3- Sensitivity analysis of d_{max} parameter

As mentioned in section3, this parameter prevents algorithm from quick convergence and to be trapped in local minima. The value of this parameter is updated after each iteration. Results of diagrams for three different values of d_{max} for a system with 10 units and load of 2700 MW are shown in Figure 7 and Table 6, respectively.

Table 7. Results of WCA for system with 10 units and load of 2700 MW and different values of d_{max}

Unit No	d_{max}=2	d_{max}=0.1	d_{max}=0.01
	Output	Output	Output
P_1 (MW)	218.5807	220.0550	216.3999
P_2 (MW)	214.1351	210.9169	211.4120
P_3 (MW)	280.6462	279.6702	284.4471
P_4 (MW)	239.2832	238.7458	240.7613
P_5 (MW)	273.7120	280.1485	278.8212
P_6 (MW)	239.1236	239.6610	237.2423
P_7 (MW)	287.7891	287.7073	289.7176
P_8 (MW)	239.9551	239.6864	240.8957
P_9 (MW)	427.5427	427.4088	425.7371
P_{10} (MW)	279.1428	275.9998	274.5656
$\boldsymbol{F_{total}}$ ($/h)	623.9863	623.8509	623.9657

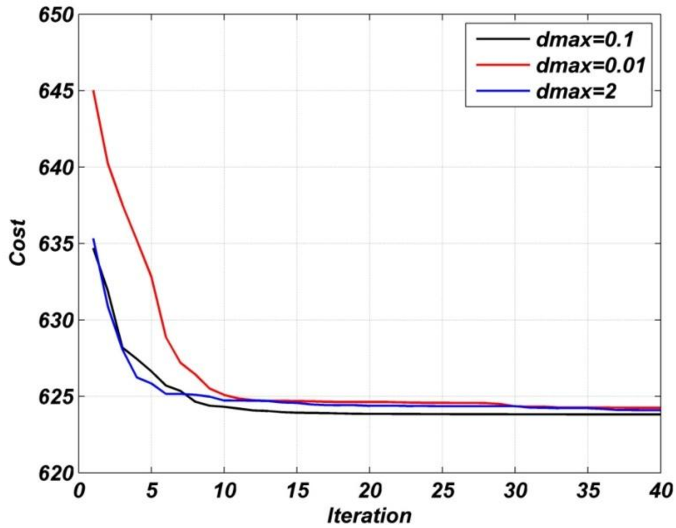

Figure 7. Sensitivity analysis diagram of WCA for system with 10 units and load of 2700 MW and parameter d_{max}

6. Conclusion

In this paper, a new algorithm is employed in order to solve the economic load dispatch problem. This algorithm uses fewer factors to reach to the optimum solution comparing to the other algorithms which causes this algorithm to solve the problems quicker while maintaining the accuracy. In order to show the capability of this algorithm in solving non-linear problems, two different systems are employed: a system with 3 units considering the valve-point effects and a system with 15 units considering ramp rate and forbidden area constraints of generators. In the first system, WCA has reached to the optimal solution in 0.81 s which is superior to other algorithm in term of execution time and fuel cost of generation units. In system with 15 units, as mentioned, first 30 executions are performed considering ramp rate and then 30 executions are done without considering ramp rate. Results show that this system in both cases i.e. with and without considering the effect of constraints has less fuel cost in comparison with other algorithm. At last, sensitivity analysis of C parameter was performed on a system with 10 units and load of 2700 MW. Results show that greater values of this parameter would increase the discovery range and expansion of the search process of the algorithm but too high values of this leads to solutions with little quality. Besides, too low values of this parameter would also lead to solution with little quality but a proper reduction in this parameter increases the convergence.

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