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A new runner root optimization algorithm for combined economic and emission dispatch considering valve-point effect

***Abstract**. This paper proposes a new metaheuristic, the runner-root algorithm (RRA), Inspired by the function of runners and roots of some plants in nature, to find the optimal solution for combined economic and emission dispatch (CEED) problem. RRA is equipped with two search tools, which are random leaps with large steps and the reset strategy escaped the local optimum. In addition, RRA is equipped with an exploitative tool to search around the current best solution with large and small steps to ensure the obtained result of global optimization. In this article, the CEED is formulated as a multi-objective issue by considering the fuel cost and the emission rate of toxic gases, taking into account certain equality and inequality constraints. The bi-objective CEED matter is converted into single objective function using price penalty factor. The validity of the proposed approach is tested on three test systems, with and without valve point effect in terms of total cost, with variable transmission losses and different loads. In order to see the effectiveness of the proposed algorithm, it has been compared with other algorithms in literature. The results show that the RRA is more powerful than other algorithms.*

Streszczenie.** W artykule zaproponowano nową metaheurystykę, algorytm biegacza-korzeń (RRA), zainspirowany funkcją biegaczy i korzeni niektórych roślin w przyrodzie, znaleźć optymalne rozwiązanie problemu połączonej gospodarki i wysyłania emisji (CEED). RRA jest wyposażony w dwa narzędzia wyszukiwania, które są losowymi skokami z dużymi krokami, a strategia resetowania wymyka się lokalnemu optimum. Ponadto RRA jest wyposażone w narzędzie eksploatacyjne do wyszukiwania aktualnie najlepszego rozwiązania z dużymi i małymi krokami, aby zapewnić otrzymany wynik globalnej optymalizacji. W tym artykule CEED jest sformułowana jako kwestia wielocelowa, biorąc pod uwagę koszt paliwa i wskaźnik emisji toksycznych gazów, biorąc pod uwagę pewne ograniczenia równości i nierówności. Dwuobiektywna sprawa CEED jest przekształcana w pojedynczą funkcję celu przy użyciu współczynnika kary cenowej. Trafność proponowanego podejścia jest testowana na trzech systemach testowych, z efektem punktu zaworowego i bez, pod względem całkowitego kosztu, ze zmiennymi stratami transmisji i różnymi obciążeniami. Aby zobaczyć skuteczność proponowanego algorytmu, został porównany z innymi algorytmami w literaturze. Wyniki pokazują, że RRA jest silniejszy niż inne algorytmy. **Nowy algorytm optymalizacji pierwiastka rozgałęźnego dla połączonej wysyłki ekonomicznej i emisji z uwzględnieniem efektu punktu zaworowego.

Keywords: Runner-Root Algorithm, combined economic and emission dispatch, Reserve constraints, Valve point effect.
Słowa kluczowe: Algorytm Runner-Root, Połączona emisja ekonomiczna i emisyjna, Ograniczenia rezerw, Efekt punktu zaworu.

Introduction

In a power System the economic dispatch problem (ECD) is to determine the optimal combination of power outputs for ails generating units, which minimize the total cost. However, the optimal ECD solution may no longer be satisfactory when environmental concerns are addressed; when the emission from fossil-fuel power plants are combined with ECD, the issue becomes a combined economic and emission dispatch (CEED). Actually, energy sources to generate mechanical power applied to the rotor shaft of generating units are fossil fuels. This causes a large amount of toxic gas emissions in the atmosphere, such as sulfur dioxide (SO_2), nitrogen oxide (NO_X) and carbon dioxide (CO_2). These gases cause serious troubles in the atmosphere such as global warming and disturbance in the ecological balance, in effect, air pollution affects not only humans but animals and plants as well. In fact, The US Air Act, the 1990 Amendment requires that the electrical services industry reduces its CO_2 emissions by 10 million tons per year and the NO_X emissions by 2 million tons per year with respect of the 1980 level. With the increase in the environmental [1].

Awareness and introduction of Kyoto protocol in 1990 Operating at minimum cost is no longer the only criterion for

Dispatching electric power and now emission minimization is

Also necessary for the generation utilities. It is important for this to be undertaken at the same time, sending out minimum emissions [1]. Several strategies have therefore been proposed to reduce the atmospheric pollution. They include the installation of post combustion cleaning equipment, switching to low emission fuels, the replacement of the aged fuel burners with cleaner ones, and dispatching with emission considerations. The first three options require the setting up of new equipment and/or modification of the existing ones that involve considerable capital outlay consequently considered as long-term options. Whilst, the latter option is preferred. The two objectives i.e., cost and emission are conflicting in nature and they both have to be considered simultaneously to find overall optimal dispatch.

This objective of the combined economy and emission problem (CEED) is to minimize the two multi-objective functions fuel cost and gas emissions, while satisfying load demand and operational constraints of the system.

Finding optimal solutions to these issues require efficient optimization algorithms Metaheuristics.

These latter being inspired by nature, are the current effective methods which have already proven their effectiveness in several areas of research. The best-known methods are Gravitational Search Algorithm (GSA)[1], hybrid metaheuristics algorithms (FA,BA,HYB) [2], the Genetic Algorithm (GA) [3] and Particle Swarm Optimization (PSO) [4], Artificial Bee Colony (ABC) [5], Flower Pollination Algorithm (FPA) [6], Cuckoo Search (CS) [7], New Global Particle Swarm Optimization (NGPSO) [8], multi-objective Differential Evolution (DE) [9], Kho-Kho optimization Algorithm (KKO)[10], Lightning flash algorithm (LFA) [11] multi-objective squirrel search algorithm(MOSSA) [12], they have been proposed to solve various complex CEED troubles.

This paper proposes the new meta-heuristic technique Runner Root (RRA) [13]. It is implemented to solve multi-objective combined economic and emission dispatch (CEED) problem while satisfying load demand and operational constraints. This multi-objective CEED difficulty is converted into a single objective function using the modified price penalty factor approach. The RRA is investigated to determine the optimal loading of generators in power systems. For small and large-scale power systems with in view of valve loading effect. Simulation results are implemented to indicate the robustness of RRA. In order to show the efficiency of the proposed approach, three test cases are discussed and compared with other algorithms in literature.

Mathematical formation of the problem

The objective of CEED problem is to find the optimal of generating units and minimizes both fuel cost and emission simultaneously while satisfying equality and inequality of the constraints. The CEED problem can be formulated as follows:

$$(1)\quad C_T = Min\ f(F_C, E_C)$$

Where C_T is the total generation cost in \$/hour, F_C is the cost function, E_C is the total emission generated by power plant.

Effect of valve point on fuel cost objective

To be more practical, the valve point effect is taken into account in the cost function of generators. The sharp increase in losses due to the wire drawing effects which occur as each steam admission valve starts to open leads to the nonlinear rippled input, output curve as shown in Fig.1. The obtained cost function based on the rippled curve is more accurate modelling. Thus, the fuel cost function of each fossil fuel generator is given as the sum of a quadratic and a sinusoidal function [6].

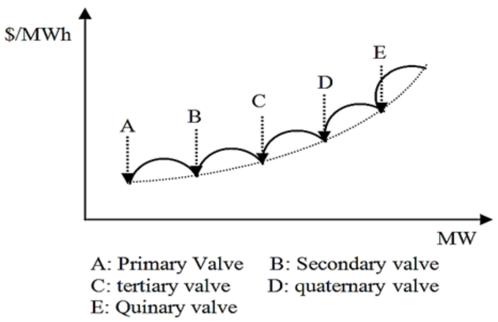


Fig. 1. Valve point effect.

Economic Dispatch (ECD)

The total fuel cost can be formulated as a quadratic function, as follows:

(2)

$$F_C = \sum_{i=1}^{m} F_i(P_i) = \sum_{i=1}^{m} \left(c_i + b_i P_i + a_i P_i^2 + \left| d_i * \sin\left\{ e_i * \left(P_i^{\min} - P_i \right) \right\} \right| \right)$$

Where P_i is the power generation of ith generator, m is the total number of generation units, c_i, b_i and a_i are fuel cost coefficients of ith generator. The coefficients d_i and e_i are the valve point effect of ith generator [9].

Emission Dispatch (ESD)

The total quantity of emissions, such as NO_X, released by the combustion of fossil fuels in thermal power plants can be defined as the sum of a quadratic function and an exponential function. the mathematical equation used is given as;

$$(3)\quad E_C = \sum_{i=1}^{m} E_i(P_i) = \sum_{i=1}^{m} \gamma_i + \beta_i P_i + \alpha_i P_i^2 + \eta_i * \exp\left(\delta_i * P_i \right)$$

Where E_C is the total emission, α_i, β_i, γ_i and δ_i are the emission coefficients of ith generator, and η_i and δ_i are the valve point effect emission of ith generator.

Combined economic and emission dispatch (CEED)

CEED consists of two objective functions, which are economic and emission dispatches. Then these two functions are combined to solve the matter. The dual-objective CEED problem is converted into single optimization issue by introducing a price penalty factor he as follows:

$$(4)\quad Min(C_T) = (w * Fc + (1 - w) * he * Ec)$$

where w is the weighting factor that can be varied between 0 and 1, and h_e is the price penalty factor.
The price penalty factor h_e which is the ratio between the maximum fuel cost and maximum emission of corresponding generator in \$/kg as follows:

$$(5)\quad h_{ei} = \frac{F_i\left(P_i^{\max}\right)}{E_i\left(P_i^{\max}\right)} \$/kg \quad , \quad i = 1, 2, ..., m$$

Détail steps to find the price penalty factor can be obtained in [2].

Problem constraints

There are two constraints in the CEED problem which are equality and inequality constraints.

Equality constraints

For power balance, an equality constraint should be satisfied. The total generated power should be the same as total load demand plus the total line loss.

$$(6)\quad \sum_{i=1}^{Ng} P_i = P_{load} + P_{loss}$$

Where P_{load} is the total load demand and P_{loss} is total power loss in transmission lines may be expressed using B matrix coefficients as follows:

$$(7)\quad P_{loss} = \sum_{i=1}^{m} \sum_{j=1}^{m} P_i B_{ij} P_j + \sum_{j=1}^{m} B_{ij} P_i + B_{00}$$

Inequality constraints

According to this, all the generating units should operate within a prescribed limit of generation. Mathematically, it is given as:

$$(8)\quad P_i^{\min} \le P_i \le P_i^{\max} \qquad i = 1, 2, ..., m$$

Where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum limits, respectively (in MW) for the production the ith unit.

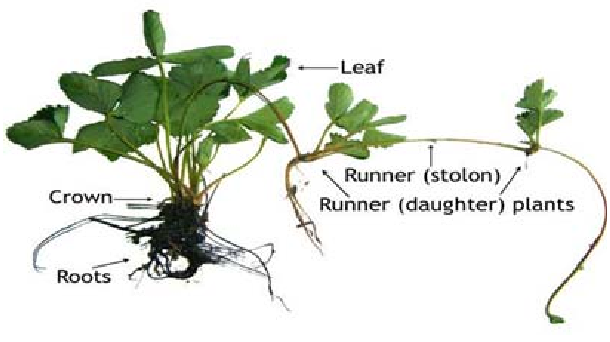


Fig.1. the function of runners and roots as tools for global searche

Runner-Root Algorithm (RRA)

The new meta-heuristic RRA developed in 2015 by Dr.F. Merrikh-Bayat [13]. Is inspired by plants such as strawberry and spider plants which are spread through their runners and also which develop roots and root hairs for local search for minerals and water resources.

Table 1. Pseudo-code of the runner-root algorithm (RRA)

Initialize $d_{runner}, d_{root}, N_{pop}, stall\_\max, tol, a$

$X^{k}_{mother}(1) \leftarrow x_1 + rand \times (x_u - x_1)$ for $k=1,...,Npop$ //initial random mother

$Stall\_count \leftarrow 0, i \leftarrow 1$

REPEAT until termination conditions are not met

$$X^{k}_{daughter}(i) = \begin{cases} X^{k}_{mother}(i) & k=1 \\ X^{k}_{mother}(i) + d_{runner} \times r_1, & k=2,...,N_{pop} \end{cases} \quad \text{for } k=1,...,N_{pop}$$

$X_{daughter,best}(i) \leftarrow \underset{x=x^{k}_{daughter}(i)}{\arg\min} f(x)$ // consumes N_{pop} function evaluation

$X = X^{k}_{daughter}(1)$

IF $i > 1$ AND $\left| \dfrac{\min_{k=1,...,N_{pop}} f(X^{k}_{daughter}(i)) - \min_{k=1,...,N_{pop}} f(X^{k}_{daughter}(i-1))}{\min_{k=1,...,N_{pop}} f(X^{k}_{daughter}(i-1))} \right| < tol$

THEN

FOR k FROM 1 UNTIL N_{pop} ***DO*** // local search with large steps

$X_{perturbed,k} \leftarrow$ diag $\{1,1,...,1,1+d_{runner} n_k, 1,...,1\} \times X_{daughter,best}(i)$

IF $f(X_{perturbed,k}) < f(X_{daughter,best}(i))$ **THEN** // consumes a function evaluation

$X_{daughter,best}(i) \leftarrow X_{perturbed,k}$

END

END $(k\text{-}loop)$

For k from 1 Until N_{pop} **DO** //local search with small steps

$X_{perturbed,k} \leftarrow$ diag $\{1,1,...,1,1+d_{root} r_k, 1,...,1\} \times X_{daughter,best}(i)$

If $f(X_{perturbed,k}) < f(X_{daughter,best}(i))$ **THEN** // consumes a function evaluation

$X_{daughter,best}(i) \leftarrow X_{perturbed,k}$

END

END $(k\text{-}loop)$

END (If)

$X^{1}_{mother}(i+1) \leftarrow X_{daughter,best}(i)$

Calculate the fitness of k-th daughter plant from

$$fit\left(X^{k}_{daughter}(i)\right) = \frac{1}{a + f\left(X^{k}_{daughter}(i)\right) - f\left(X_{daughter,best}(i)\right)}$$

and the probability of choosing it

from $p_k = \dfrac{fit\left(X^{k}_{daughter}(i)\right)}{\sum_{J=1}^{N_{pop}} fit\left(X^{j}_{daughter}(i)\right)}$ **for** $k=1,...,Npop$

FOR k FROM 2 UNTIL N_{pop} **DO** ***//*** genererating the mother plants of next iteration

$X^{k}_{mother}(i+1) \leftarrow X^{ind}_{daughter}(i)$ Where *ind* is the index of the daughter plant selected among

The daughter plants of current iteration using roulette wheel

END (k-loop)

IF $\left| \dfrac{f(\mathbf{X}_{daughter,best}(i)) - f(\mathbf{X}_{daughter,best}(i-1))}{f(\mathbf{X}_{daughter,best}(i-1))} \right| < tol$ **THEN**//checking for stall condition

$Stall\_count \leftarrow stall\_count + 1$

ELSE

$Stall\_count \leftarrow 0$

END

IF stall count > stall max **THEN** restart the algorithm (that is, memorize the best solution obtained in the current iteration for comparing purposes, go to the second line of algorithm and discard all the solutions obtained in the current iteration. The function evaluations consumed before re-initialization counted toward cumulative.)

$i \leftarrow i+1$

END (repeat)

Similar to other metaheuristics, RRA does not apply same number of function evaluation at all iterations. More precisely, for optimal solution (exploitation procedure) in RRA, global search is performed at all iterations, while local search is performed only when global search does not lead to a significant improvement in the value of cost function.

The RRA has been adopted in this paper to solve CEED problems. There are mainly three principal rules during the search process of the RRA method as follows:

1. Each mother plant is reproduced through its runners. The daughter plants are formed from the runners in a new location to explore new resources.
2. Each mother plant generates roots and root hairs randomly to explore resources around the new location.
3. At richer resources, the daughter plants will grow faster and generate more other daughter plants. Otherwise, the daughter plants will die if they move toward poor resources.

Results and Discussion

RRA is employed to solve CEED problem for three different cases to assure its optimization efficiency, where the objective function is limited by the outputs limits of generation units and transmission losses. The performance of RRA is compared with various optimization algorithms. For this purpose, we developed programs in MATLAB 7.9 environment.

Test case 1

This case consists of three generating units with quadratic cost and emission level functions. The fuel cost coefficients, emission coefficients, generators constraints, load demands, and the transmission loss matrix coefficient are given in [2]. Each demand has his own price penalty factor he, 43.55981 $/kg and 44.07915 $/kg, 400MW and 500MW. Respectively.The simulation results are in Table 1.

For test case1 the best results of CEED for various load demands using the proposed RRA their comparison with other algorithms such as GA [3] and FPA [6] are also presented and compared in Table 2 and Fig 2.

Two axes shapes are formed consisting of fuel cost and emission values for a better understanding of the CEED problem.

Fig. 2 and Fig. 3 show the total cost associated with RRA for various demands.

Table 2. Results of CEED for three-unit system

Power outputs	GA [3]	FPA [6]	RRA
P1 (MW)	102.617	102.4468	102.6736
P2 (MW)	153.825	153.8341	153.6225
P3 (MW)	151.011	151.1321	151.0970
P_{loss} (MW)	7.41324	7.4126	7.4109
P_{load} (MW)		400	
Fuel Cost ($/hr)	20840.1	20838.1	20837.7661
Emission (kg/hr)	200.256	200.2238	200.1981
Total cost ($/hr)	29563.2	29559.81	29558.3533
P1 (MW)	128.997	128.8074	128.8438
P2 (MW)	192.683	192.5906	192.5570
P3 (MW)	190.11	190.2958	190.2476
P_{load} (MW)		500	
P_{loss} *(MW)*	11.6964	11.6938	11.6913
Fuel Cost ($/hr)	25499.4	25494.77	25492.73
Emission (kg/hr)	311.273	311.155	311.0981
Total cost ($/hr)	39220.1	39210.15	39205.6894

From the results of Table 2 it is clear that the proposed approach yielded a minimum total cost, better than the total cost found by other algorithms and that even with the change of the load, moreover, the equality and inequality constraints are accomplished.

The Proposed RRA gives the best results, regarding both fuel costs and emissions for the CEED problem.

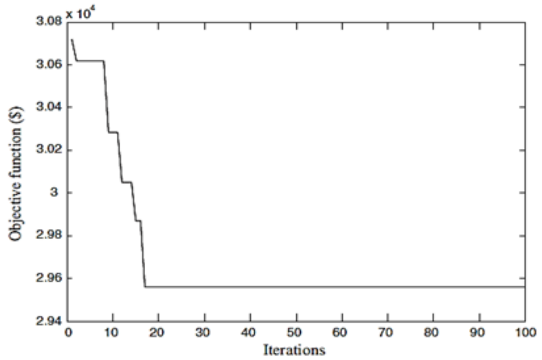
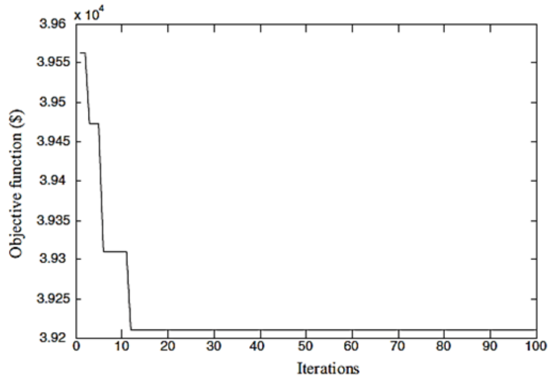


Fig. 2. Objective function for 3 unit system with demand = 400



MW.

Fig. 3. Objective function for 3 unit system with demand = 500 MW.

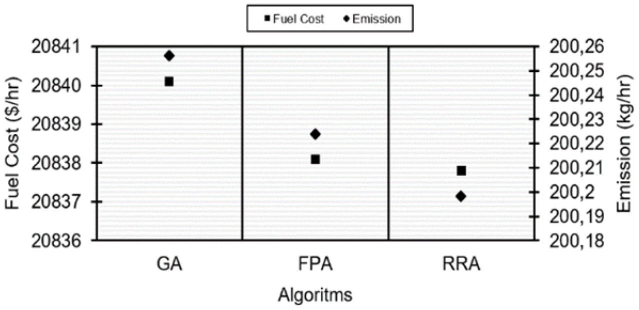


Fig.4.Comparison CEED for various algorithms with P_{load}=400MW

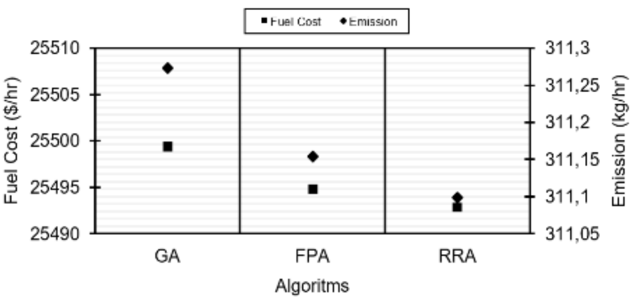


Fig.5.Comparison CEED for various algorithms with P_{load}=500MW

Test case 2

This system consists of eleven generating units, having quadratic cost and emission functions. The input data for the 6-generator system are taken from [2] and the total demand is set as 1000 MW. The results obtained from the proposed RRA for this case are presented and compared to other with (FA,BA,HYB) [2] for best economic and environmental situations in Table 3.

Table 3. Results of CEED for test case 2 (P_{load} = 1000 MW)

Power outputs	FA [2]	BA [2]	HYB [2]	RRA
P1 (MW)	107.1685	107.1631	107.1613	107.2236
P2 (MW)	116.5498	116.5483	116.5507	116.6909
P3 (MW)	165.6550	165.6599	165.6535	165.5926
P4 (MW)	163.4014	163.4001	163.4032	163.2578
P5 (MW)	242.0380	242.0355	242.0460	242.2924
P6 (MW)	239.7979	239.8036	239.7958	239.3996
P_{loss} (MW)	34.6112	34.6113	34.6113	34.5961
Fuel Cost ($/h)	54124.28	54124.12	54124.13	54121.101
Emission (kg/h)	851.53	851.53	851.53	851.1942

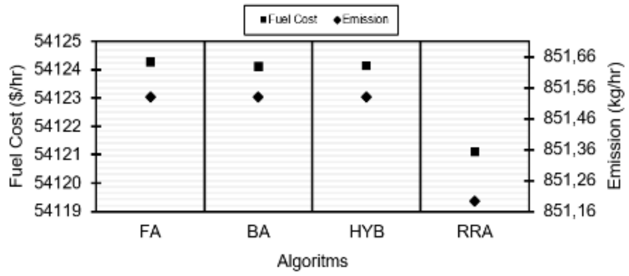


Fig.6. Comparison CEED for various algorithms for test case 2.

Test case 3

This case studies ten generating units considering valve point effects. The fuel cost coefficients, emission coefficients, generators constraints, and the transmission loss matrix coefficient are shown in [1]. Table 4 shows the results of solving CEED for 2000 MW load demand using RRA and comparing with other stochastic search algorithms such as

GSA [1], LFA [10], MOSSA [11]. The compromised fuel cost and emission obtained by the RRA approach are112995.6772 $ and 4123.68 kg, respectively. The results obtained from the proposed approach are better than other optimization algorithms (Fig. 7). The proposed RRA yields a lower cost than GSA, LFA, MOSSA by 494$,250$,36$ respectively while achieving the constraints of system. Its emission is also lower than LFA, MOSSA, which is more than GSA.

Table 4. Results of CEED for test case 3 (P_{load} = 2000 MW)

Power outputs	GSA [1]	LFA [11]	MOSSA [12]	RRA
P1 (MW)	54.9992	54.9920	55.5760	78.3491
P2 (MW)	79.9586	78.7689	79.6212	83.9672
P3 (MW)	79.4341	87.7168	80.8269	84.5045
P4 (MW)	85.0000	78.1055	84.9306	82.9525
P5 (MW)	142.1063	140.6272	133.6299	132.9546
P6 (MW)	166.5670	157.0936	161.4188	151.6375
P7 (MW)	292.8749	299.9954	291.6939	296.6825
P8 (MW)	313.2387	309.2219	315.7878	314.8520
P9 (MW)	441.1775	439.3243	445.0623	428.1623
P10 (MW)	428.6306	438.6947	434.4524	430.0299
P_{loss} (MW)	-	84.37	-	84.17
Fuel Cost ($/hr)	113490	113246	113032.1069	112995.6772
Emission (kg/hr)	4111.4	4139.89	4139.0930	4123.68

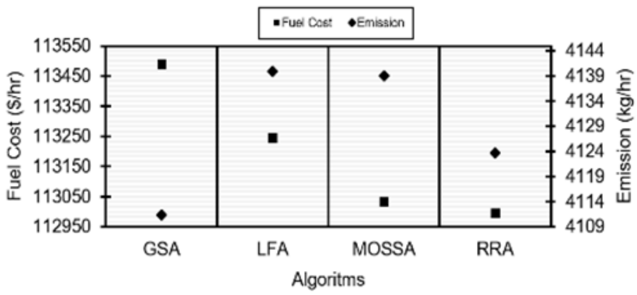


Fig.7. Comparison CEED for various algorithms for test case 3.

Conclusion :

In this paper, a new optimization algorithm known as RRA has been proposed to solve the combined economic emission dispatch (CEED) problem for different power systems and load demands. The results obtained by the proposed method are compared with various optimization algorithms. The comparison assures the superiority of RRA over other algorithms for settling CEED problem even for large scale power system with valve point effect. Moreover, the economic effect, computation efficiency and convergence property of RRA are demonstrated. Therefore, RRA optimization is a promising technique for solving complicated problems in power systems. Applications of the proposed algorithm to multi-area power system integrated with wind farms and PV system are the future scope of this work.

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