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ORIGINAL ARTICLE

An economic load dispatch and multiple environmental dispatch problem solution with microgrids using interior search algorithm

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Abstract Microgrid is a novel small-scale system of the centralized electricity for a small-scale community such as villages and commercial area. Microgrid consists of micro-sources like distribution generator, solar and wind units. A microgrid is consummate specific purposes like reliability, cost reduction, emission reduction, efficiency improvement, use of renewable sources and continuous energy source. In the microgrid, the Energy Management System is having a problem of Economic Load Dispatch (ELD) and Combined Economic Emission Dispatch (CEED) and it is optimized by meta-heuristic techniques. The key objective of this paper is to solve the Combined Economic Emission Dispatch (CEED) problem to obtain optimal system cost. The CEED is the procedure to scheduling the generating units within their bounds together with minimizing the fuel cost and emission values. The newly introduced Interior Search Algorithm (ISA) is applied for the solution of ELD and CEED problem. The minimization of total cost and total emission is obtained for four different scenarios like all sources included all sources without solar energy, all sources without wind energy and all sources without solar and wind energy. In both scenarios, the result shows the comparison of ISA with the Reduced Gradient Method (RGM), Ant Colony Optimization (ACO) technique and Cuckoo Search Algorithm (CSA) for the two different cases which are ELD without emission and CEED with emission. The results are calculated for different Power Demand of 24 h. The results obtained to ISA give comparatively better cost reduction as compared with RGM, ACO and CSA which shows the effectiveness of the given algorithm.

Keywords Microgrid · Economic load dispatch · Emission dispatch · Wind generation prediction · Solar generation prediction · Interior search algorithm

1 Introduction

Electrical power utilities need to guarantee that electrical power necessity from the consumer end is fulfilled in accordance with the reliable power quality and minimum cost. Due to increasing technological research, industrial development and population, the power demand increases. With increasing electrical power demand worldwide, the non-renewable energy sources are reducing day after day. To solve the problem of increasing electrical power demand should be fulfilled by clean renewable energy sources (RES). With the use of more renewable energy sources, the power generation can be increased which is the modern research scenario at the present time. In this research, there is a more use of distributed energy resources in a specific small area which is known as a microgrid. Microgrid consists of micro-sources (distribution generator, solar and wind units, etc.), battery storage and loads.

Every utilities desire that generation cost and emission value should be as least as possible, but both objectives are contradictory so cannot be achievable at a same time. In

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this paper term used Combined Economic Emission Dispatch (CEED) problem. In the past, there is only objective to minimize cost while generation of power, but now a big concern about saving environment and human health from pollution to rectify problem of global warming, so some rules are imposed on private and government utilities to reduce emission of toxic gases exhalation with possible least fuel cost [1].

Various conventional linear optimization methods were used to solve the Economic Load Dispatch (ELD) problem [2]: (a) lambda-iteration method, (b) gradient method, (c) linear programing method and (c) Newton's method. Linear programing techniques are fast and reliable, but these methods are failed to obtain the optimal solution for solving highly complex nonlinear objective function.

Interior Search Algorithm (ISA) technique guarantees to obtain global solution, and algorithm has a capability to avoid local stagnation or local optima [3]. The multi-objective power system dispatch problem can be transformed into single objective by Scalarization methods (Priori Approach) using these techniques [1]:

- Price penalty factor technique
- Weighted sum method (WSM)
- Goal Attainment method
- Lexicographic method

The CEED problem consists of either single objective or multi-objective is solved using various algorithms such as: After Scalarization technique is applied, CEED problem can be classified into two forms with and without considering valve-point effect loading of generators further classified into equation used either quadratic and cubic equation to evaluate fuel cost and emission value. CEED problem can be solved without considering valve-point effect and with price penalty factors based approach is solved with various computational techniques [2].

The CEED problem is solved using "Max–Max" price penalty factor approach by various Artificial Intelligence (AI) techniques [4] consisting of Genetic Algorithm (GA), Evolutionary Programming (EP), Particle Swarm Optimizer (PSO) and Differential Evolution (DE) is applied on IEEE-30 bus system. "Max–Max" price penalty factor is also used to solve CEED problem with Gravitational Search Algorithm (GSA) [5], Parallelized PSO (PPSO) [6], Evolutionary Programming (EP), Micro-GA (MGA) [7], Assessment of available transfer capability for practical power system with CEED problem for IEEE-30 bus system with 6 generating units and Indian Utility System 62-bus (IUS-62) with nineteen generators [8]. Analytical solution for CEED problem with IUS-62 with six generators, comparative study [9] with "Min–Max" price penalty factor using PSO and Lagrange's Algorithm (LA), with LA [10] and PSO [11] taking "Min–Max" and "Max–Max" price penalty factors approach CEED problem is solved. Lagrange's algorithm is used to solve CEED problem with four penalty factors [12] with quadratic equation is considered for evaluating fuel cost and emission value, six penalty factors with cubic equation [13] used for the calculation of CEED problem. Scenario-based dynamic economic emission dispatch problem is solved by Fuzzy adaptive improved PSO (FAIPSO) [14]. CEED problem with valve-point effect is solved by using "Min–Max" and "Max–Max" price penalty factors approach with LA [15], Maclaurin series-based Lagrangian method [16], Opposition-based GSA (OGSA) [17].

Various types of economic dispatch problem are solved with weighted sum method (WSM) using PSO [18]. CEED problem with WSM technique is solved using Artificial Bee Colony (ABC) algorithm with Dynamic Population size (ABCDP) [19] algorithm and opposition-based harmony search algorithm (OHS) [20]. Hybridization of PSO and GSA computational techniques with weighted sum method considers valve-point effect [21] for CEED problem solution. Neural network, Fuzzy system and Lagrange's algorithm (LA) [22] for single- and multi-area dispatch problem investigate Emission Standards [23], Location of Greenhouse gases (GHG) emission from thermal power plant in India [24], Dispatch problem on different power system using Stochastic algorithm [25, 26], Security-constrained economic scheduling of generation considering generator constraints [27, 28], Integration of solar and coal-fired plant [29].

Finally, the future of economic environmental emission dispatch problem is multi-objective (such as: fuel cost, emission value, CEED fuel cost, different gases exhalation) considering at a single time to find actual operating point of generators to fulfil all objectives efficiently. Multi-objective thermal power dispatch [30], considering more than one objective for CEED problem, is solved using various computational techniques such as: multi-objective DE (MODE) [31], MOGSA [32], modified non-dominated sorting genetic algorithm-II (MNSGA-II) [33], NSGA-II with valve-point effect [34], BB-MOPSO [35], hybrid multi-objective optimization algorithm based on PSO and DE (MO-DE/PSO) [36], multi-objective particle swarm optimization algorithm proposed by Coello et al. (CMOPSO) [37], multi-objective particle swarm with the sigma method (SMOPSO) [38] and time variant multi-objective particle swarm optimization (TV-MOPSO) [39].

In this paper, the analysis of islanded mode microgrid (MG) is considered. The Combined Economic Emission Dispatch (CEED) is the procedure to scheduling the generating units within their bounds together with the minimization of fuel cost and emission [40]. The CEED is an elementary problem in the microgrid, which can be optimized by meta-heuristic optimization techniques like Ant Colony Optimization (ACO) [41] technique and Cuckoo Search Algorithm (CSA) [42]. Hence, for the solution of ELD and CEED problem, Interior Search Algorithm (ISA) [43, 44] is used. Many optimization strategies have been incorporated into the basic algorithm, such as chaotic theory [53, 54], Stud [55], quantum theory [56], Lévy flights [57, 58], multi-stage optimization [59] and opposition-based learning [60]. Many other excellent meta-heuristic algorithms have been proposed, such as monarch butterfly optimization (MBO) [61, 62], earthworm optimization algorithm (EWA) [63], elephant herding optimization (EHO) [64], moth search (MS) algorithm [65].

This paper Structure is, Sect. 1: Paper introduction, Sect. 2: Microgrid structure, Sect. 3: Mathematical model of isolated mode microgrid, Sect. 4: Interior Search Algorithm, Sect. 5: Data of microgrid, Sect. 6: Results of microgrid and Sect. 7: Conclusion.

2 Microgrid structure

Microgrid is modern micro-scale power system of the centralized electricity for a small community such as villages and commercial area [45]. A microgrid is consummate specific purposes like reliability, cost reduction, emission reduction, efficiency improvement, use of renewable sources and continuous energy source [46]. Figure 1 displays a microgrid including every distributed energy sources, and all loads are coupled to the main grid. Microgrid consists of DG units like wind unit, solar unit, hydro unit, biomass unit, natural gas generator, diesel generator, combined heat and power(CHP) and battery energy storage. The microgrid also connected different types of loads like agriculture, industrial, commercial, residential, university and vehicle charging. The microgrid is connected to the micro-sources and supply produced power to the different loads through the point of common coupling (PCC) [47].

The main advantage of a microgrid is to combine all benefits of renewable energy sources to reduce the carbon generation and power generation efficiency improvement. Microgrid has two modes of connection: first is Grid coupled mode, and second is isolated mode [48]. In the first mode, microgrid is connected to the main grid via PCC. In the isolated mode, a microgrid is not connected from the main grid.

Micro-source controllers used in microgrid control the micro-source and loads. In the isolated mode, microgrid is isolated from the utility grid and delivers power to the important loads. Rating of these critical loads is considered equal to 240 MW [40].

Figure 2 explains why there is a need of microgrid in power system. Microgrid is an answer of energy crisis in the power system [45]. Reduced transmission loss to the DERs (microgrid) connection of transmission line in different location. Power generation cost is reduced using

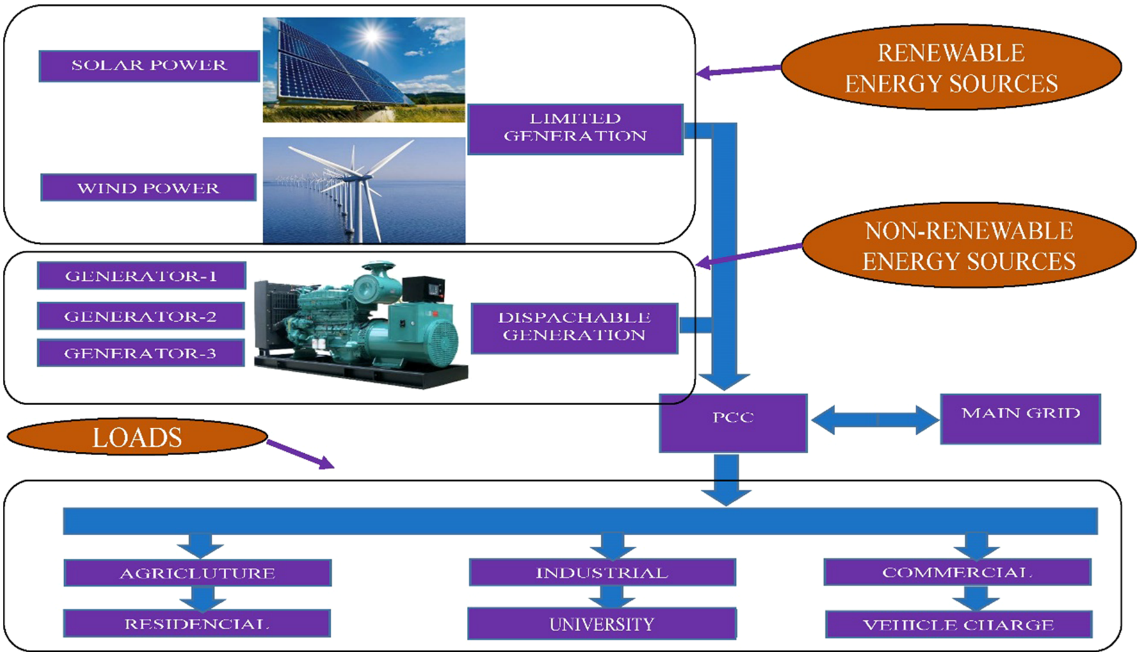


Fig. 1 Microgrid structure

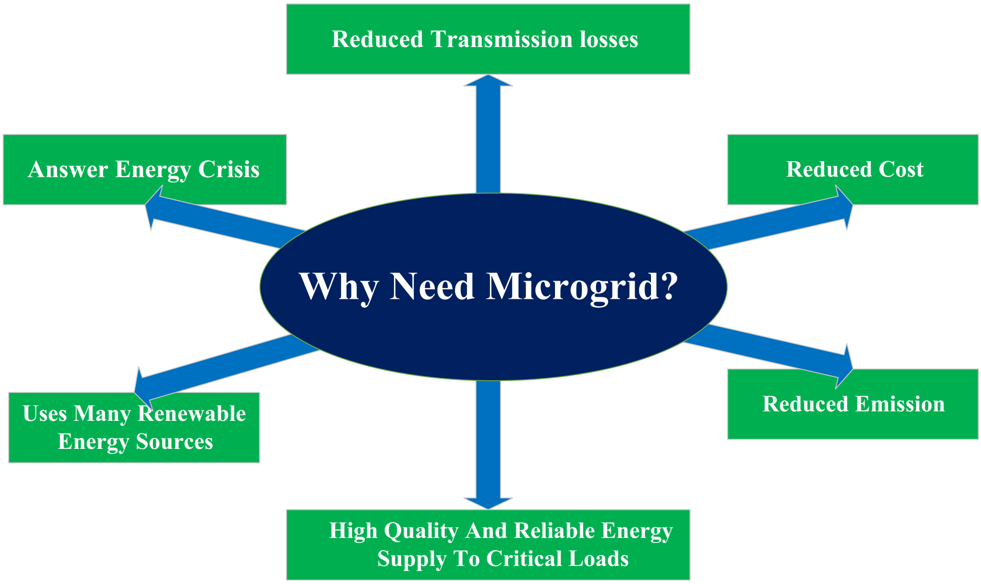


Fig. 2 Why need microgrid in the power system

distributed energy resources in microgrid as well as microgrid uses many renewable energy resources. Environmental emission is more reduced to be using microgrid in power system and achieve high quality and reliable energy supply to the critical loads.

3 Mathematical model of isolated mode microgrid

3.1 Generator fuel cost function

The main objective of the Economic Load Dispatch (ELD) problem solution is to examine the generation levels of every on-line unit which decreases the total generation fuel cost and reduces the emission level of the system, together with satisfying a system constraint [47]. The objective of ELD is to reduce the generation fuel cost together with satisfying the power demand of a modern power system during a given duration of time considering the power system operating constraints. The ELD problem fuel cost function of Generators quadratic equation is [49]:

$$\mathrm{Min}(F_C) = \sum_{i=1}^{NG} u_i P_i^2 + v_i P_i + w_i \tag{1}$$

where F_C = Total fuel cost, NG Number of generators, P_i = Active power generation of ith generator, u_i = Cost coefficient of ith generator in [\$/MW^{2}h], v_i = Cost coefficient of ith generator in [\$/MWh], w_i = Cost coefficient of ith generator in [\$/h].

The various pollutants like carbon dioxide, sulphur dioxide and nitrogen oxide are released as a result of the operation of the diesel generator, gas generator, CHP [1, 2]. Reduction of these pollutants is compulsory for every generating unit. To achieve this goal, new criteria are included in the formulation of the Emission Dispatch problem as follows.

$$E_T = \sum_{i=1}^{n} \left(x_i P_i^2 + y_i P_i + z_i \right) \tag{2}$$

where E_T = Total Emission Value, x_i = Emission coefficient of ith generator in [kg/MW^{2}h], y_i = Emission coefficient of ith generator in [kg/MWh], z_i = Emission coefficient of ith generator in [kg/h].

Price Penalty Factor (PPF) *hi* is used to convert multi-objective CEED problem into a single-objective optimization problem [1].

$$F_T = \sum_{i=1}^{n} \left[\left(u_i P_i^2 + v_i P_i + w_i \right) + h_i \left(x_i P_i^2 + y_i P_i + z_i \right) \right] \tag{3}$$

where F_T = Total CEED Cost, h_i = Price Penalty Factor (PPF).

The function of PPF is to transfer the physical sense of emission measure from the mass of the emission to the fuel cost for the emission. The variance among these penalty factors is in the fuel cost mass for emission in the last optimal fuel cost for generation and emission. The PPF for multi-objective ELD problem is formulated taking the ratio of fuel cost to emission value of the corresponding generators as follows [13, 15].

Table 1 Solar generation

Time (h)	Solar generation (MW)	Time (h)	Solar generation (MW)	Time (h)	Solar generation (MW)
1	0	9	24.05	17	9.57
2	0	10	39.37	18	2.31
3	0	11	7.41	19	0
4	0	12	3.65	20	0
5	0	13	31.94	21	0
6	0.03	14	26.81	22	0
7	6.27	15	10.08	23	0
8	16.18	16	5.30	24	0

Table 2 Wind generation

Time (h)	Wind generation (MW)	Time (h)	Wind generation (MW)	Time (h)	Wind generation (MW)
1	1.7	9	20.58	17	3.44
2	8.5	10	17.85	18	1.87
3	9.27	11	12.80	19	0.75
4	16.66	12	18.65	20	0.17
5	7.22	13	14.35	21	0.15
6	4.91	14	10.35	22	0.31
7	14.66	15	8.26	23	1.07
8	26.56	16	13.71	24	0.58

Min–Max price penalty factor is formulated as:

$$h_i = \frac{\left(u_i P_{i\min}^2 + v_i P_{i\min} + w_i\right)}{\left(x_i P_{i\max}^2 + y_i P_{i\max} + z_i\right)} \quad (\$/\mathrm{h}) \tag{4}$$

3.2 Solar generation prediction

The cost function is [48, 49]:

$$F(P_{\mathrm{Solar}}) = aI^p P_{\mathrm{Solar}} + G^E P_{\mathrm{Solar}} \tag{5}$$

$$a = \frac{r}{\left[1 - \left[(1+r)^{-N}\right]\right.} \tag{6}$$

where P_{Solar} = Solar generation in [kW], r = Interest scale = 0.09, a = Annuitization coefficient, N = Investment duration = 20 years, I^p = Ratio of Investment cost to unit establish power = 5000\$/kW, G^E = Operational cost and maintenance cost = 0.016\$/kW.

The cost function for solar energy can be calculated as:

$$F(P_{\mathrm{Solar}}) = 547.7483 * P_{\mathrm{Solar}} \tag{7}$$

The 24 h' data of solar generation are shown in Table 1. In this case, we have considered the solar generation data [50] of a location in the east coast of USA, as shown in Table 1.

3.3 Wind generation prediction

The cost function is [51]:

$$F(P_{\mathrm{Wind}}) = aI^p P_{\mathrm{Wind}} + G^E P_{\mathrm{Wind}} \tag{8}$$

$$a = \frac{r}{\left[1 - \left[(1+r)^{-N}\right]\right.} \tag{9}$$

where P_{Wind} = Wind generation in [kW], r = Interest scale = 0.09, a = Annuitization coefficient, N = Investment duration = 20 years, I^p = Ratio of Investment cost to unit establish power = 1400\$/kW, G^E = Operational cost and maintenance cost = 0.016\$/kW.

The cost function for wind energy can be calculated as:

$$F(P_{\mathrm{Wind}}) = 153.3810 * P_{\mathrm{Wind}} \tag{10}$$

The 24 h' data of wind generation are shown in Table 2. In this case, we have considered the wind generation data [50] of a location in the east coast of USA, as shown in Table 2.

3.4 Total cost of economic dispatch (ELD) and combined economic emission dispatch (CEED) in microgrid

3.4.1 Total cost of economic load dispatch (ELD)

$$\mathrm{Min}(F_C) = \sum_{i=1}^{NG} u_i P_i^2 + v_i P_i + w_i + 153.3810 * P_{\mathrm{Wind}} + 547.7483 * P_{\mathrm{Solar}} \tag{11}$$

3.4.2 Total cost of combined economic emission dispatch (CEED)

$$F_T = \sum_{i=1}^{n} \left[\left(u_i P_i^2 + v_i P_i + w_i\right) + h_i\left(x_i P_i^2 + y_i P_i + z_i\right)\right] + 153.3810 * P_{\mathrm{Wind}} + 547.7483 * P_{\mathrm{Solar}} \tag{12}$$

3.5 Constraint function

(a) *Isolated type of MG:*

No trading of energy from the main grid [52].

(b) *Power Balance constraint:*

$$P_{\mathrm{Load}} = P_1 + P_2 + P_3 + P_4 + P_5 \tag{13}$$

(c) *Power Generation constraint:*

Each generator output bounded by minimum and maximum boundaries [52].

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{14}$$

$P_i^{\max}$ = Max. output power of ith generator, $P_i^{\min}$ = Min. output power of ith generator.

4 Interior search algorithm

Interior Search Algorithm (ISA) technique guarantees to obtain global solution, and algorithm has a capability to avoid local stagnation or local optima [3]. ISA is a combined optimization analysis divine to the creative work or art relevant to interior or internal designing [3] consisting of two stages: first one is composition stage where a number of solutions are shifted towards to get optimum fitness. The second stage is reflector or mirror inspection method where the mirror is placed in the middle of every solution and best solution to yield a fancy view to design, satisfying all control variables to constrained design problem.

1. However, the position of acquired solution should be in the limitation of maximum bound and minimum bounds, later estimate their fitness amount [3].
2. To evaluate the best value of the solution, the fittest solution has maximum objective function whenever aim of the optimization problem is minimization and vice versa is always true. The solution has universally best in jth run (iteration).
3. Remaining solutions are collected in two categories mirror and composition elements with respect to a control parameter α. Elements are categorized based on the value of random number (all used in this paper) ranging [0, 1].
   Whether $rand_1()$ is less than or equal to α, it moves to mirror category else moves towards composition category. For avoiding problems, α must be carefully tuned.
4. Being Composition category elements, every element or solution is, however, transformed as described below in the limited uncertain search space.

Table 3 Generation of power min–max limits [40]

	Min. power (MW)	Max. power (MW)
Generator-1	37	150
Generator-2	40	160
Generator-3	50	190

Table 4 Fuel cost coefficient of three generators [48]

	u ($/MW^{2}h))	v ($/MWh)	w ($/h)
Generator-1	0.024	21	1530
Generator-2	0.029	20.16	992
Generator-3	0.021	20.4	600

Table 5 Emission coefficient of three generators [48]

	x (kg/MW^{2}h)	y (kg/MWh)	z (kg/h)
Generator-1	0.0105	−1.355	60
Generator-2	0.008	−0.6	45
Generator-3	0.012	−0.555	30

$$x_i^j = lb^j + (ub^j - lb^j) * r_2 \tag{15}$$

where x_i^j represents ith solution in jth run, ub^j and lb^j upper and lower ranges in jth run, whereas its maximum and minimum values for all elements exist in $(j-1)$th run and $\text{rand}_2()$ ranging [0, 1].

5. For ith solution in jth run, spot of mirror is described [43]:

$$x_{m,i}^j = r_2 x_i^{j-1} + (1 - r_3) * x_{gb}^j \tag{16}$$

where $rand_3()$ ranging [0, 1]. Imaginary position of solutions is dependent on the spot where mirror is situated defined as:

$$x_i^j = 2x_{m,i}^j - x_i^{j-1} \tag{17}$$

6. It is auspicious for universally best to little movement in its position using uncertain walk defined:

$$x_{gb}^j = x_{gb}^{j-1} + r_n * \lambda \tag{18}$$

where r_n a vector of distributed random numbers having the same dimension of x, $\lambda = (0.01*(\text{ub} - \text{lb}))$ scale vector, dependable on search space size.

7. Evaluate fitness amount of new position of elements and for its virtual images. Whether its fitness value is enhanced, then position should be updated for next design. For minimization optimization problem, updating are as follows [44]:

$$x_i^j = \begin{cases} x_i^j \,..f\left(x_i^j\right) < f\left(x_i^{j-1}\right) \\ x_i^{j-1} \,......Else \end{cases} \tag{19}$$

8. If termination condition not fulfilled, again evaluate from the second step.

A. *Parameter tuning*

A curious component in algorithm is α. For unconstrained benchmark test function, it is almost fixed 0.25, but the

Table 6 24-h load demand [50]

Time (h)	Load (MW)	Time (h)	Load (MW)	Time (h)	Load (MW)
1	140	8	210	17	170
2	150	10	230	18	185
3	155	11	240	19	200
4	160	12	250	20	240
5	165	13	240	21	225
6	170	14	220	22	190
7	175	15	200	23	160
8	180	16	180	24	145

Table 7 All sources included

Time (h)	PD (MW)	Generation (MW)			RGM cost ($/h) [40]	ACO cost ($/h) [40]	CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3				
1	140	48	40	50	6297	6134	6117	6117
2	150	51	40	50	6474	6312	6192	6192
3	155	56	40	50	6565	6439	6291	6292
4	160	54	41	51	6650	6512	6235	6234
5	165	63	44	50	6759	6682	6573	6575
6	170	64	48	51	6867	6807	6742	6735
7	175	62	42	50	7209	6837	6487	6488
8	180	47	40	50	7762	6780	6093	6093
9	210	65	50	51	8649	7457	6758	6750
10	230	67	52	54	9713	7852	6930	6936
11	240	74	68	77	8722	8358	8026	8026
12	250	76	71	80	8794	8594	8216	8213
13	240	70	59	65	9654	8146	7425	7408
14	220	68	57	58	9013	7760	7154	7154
15	200	68	55	59	7905	7424	7126	7129
16	180	64	46	52	7268	6943	6648	6649
17	170	62	44	50	7276	6756	6555	6553
18	185	68	55	57	7288	7146	7107	7107
19	200	71	61	67	7544	7538	7530	7525
20	240	77	75	86	8567	8517	8510	8510
21	225	75	70	79	8167	8153	8150	8148
22	190	69	58	62	7314	7316	7313	7313
23	160	63	46	50	6674	6605	6599	6599
24	145	54	41	50	6389	6275	6267	6266
Total	4580	1536	1243	1399	183,520	173,343	167,044	167,012

requirement is to increase its value ranging [0, 1] randomly as the increment in a maximum number of runs selected for a particular problem. It requires shifting search emphasized from exploration stage to exploitation optimum solution towards termination of maximum iteration.

B. *Constraint manipulation*

Evolutionary edge (boundary) constraint manipulation:

$$f(z_i \to x_i) = \begin{cases} r_4 * lb_i + (1 - r_4) x_{gb,i} \ldots if \ldots z_i < lb_i \\ r_5 * ub_i + (1 - r_5) x_{gb,i} \ldots if \ldots z_i < ub_i \end{cases} \tag{20}$$

where r_4 and $r_5 =$ random numbers between [0, 1]. $x_{gb,i} =$ Component of the global best solution.

C. *Nonlinear constraint manipulation*

Nonlinear Constraint manipulations have following rules:

I. Both solutions are possible, then consider one with best objective functional value.
II. Both solutions are impossible, then consider one with less violation of constraints.

Evaluation of constraint violation:

$$V(x) = \sum_{k=1}^{nc} \frac{g_k(x)}{g_{\text{maxk}}} \tag{21}$$

where $\text{nc} = \text{No. of constraints}$, $g_k(x) = k^{th}$ constraint consisting problem, $g_{\text{max}k} =$ The maximum violation in kth constraint yet.

Control Parameter of ISA, CSA and ACO

Control parameter of ISA, CSA and ACO is Population Size: 40, Maximum Iteration (N): 500, Number of Variable (d): 3, Random Number (r): [0, 1].

Pseudo-code of Algorithm [44]

```
Initialization
while any stop criteria are not satisfied
    find the $x_{gb}^{j}$
    for i = 1 to n
        if $x_{gb}$
            Apply Eq. $x_{gb}^{j} = x_{gb}^{j-1} + r_n * \lambda$
        else if $r_1 > \alpha$
            Apply Eq. $x_i^j = LB^j + (UB^j - LB^j) * r_2$
        else
            Apply Eq. $x_{m,i}^{j} = r_2 x_i^{j-1} + (1 - r_3) * x_{gb}^{j}$
            Apply Eq. $x_i^j = 2x_{m,i}^{j} - x_i^{j-1}$
        end if
        Check the boundaries except for decomposition elements.
    end for
    for i = 1 to n
        Evaluate $f(x_i^j)$
        Apply Eq. $x_i^j = \{ \begin{matrix} x_i^j \ldots f(x_i^j) < f(x_i^{j-1}) \\ x_i^{j-1} \end{matrix}$
        else
    end for
end while
```

5 Data of microgrid

The minimum limit and maximum limit of the output power of all micro-sources are shown in Table 3.

Table 4 shows fuel cost coefficient of three generators.

Table 5 shows emission coefficient of three generators.

Table 6 shows the system power demand for 24 h of a day.

6 Results of microgrid

6.1 All sources included

6.1.1 Without emission (ED)

Table 7 shows results of cost and generation of 24 h for the case when all sources included. This table also shows comparative study of generation cost obtained from CSA and ISA with respect to prior solved techniques RGM and ACO. Statistically aggregated 24-hour generation cost for ED case in comparative study clearly proves that lowest cost is obtained with ISA compared to other techniques.

6.1.2 With emission (CEED)

Table 8 shows results of cost and generation of 24 h for the case when all sources included. This table also shows comparative study of generation cost obtained from CSA and ISA with respect to prior solved techniques RGM and ACO. Statistically aggregated 24-hour generation cost for CEED case in comparative study clearly proves that lowest cost is obtained with ISA compared to other techniques.

Figure 3 shows the comparison of cost saving of ED and CEED using ISA with different algorithms like RGM, ACO and CSA. Aggregated cost saving for all sources included ISA with respect to GM, ACO and CSA is 20.70, 13.21 and 0.03%, respectively.

6.2 All sources without wind energy

6.2.1 Without emission (ED)

Table 9 shows results of cost and generation of 24 h for the case when all sources included without wind energy. This table also shows comparative study of generation cost obtained from CSA and ISA with respect to prior solved techniques RGM and ACO. Statistically aggregated

Table 8 All sources included

Time (h)	PD (MW)	Generation (MW)			RGM cost ($/h) [40]	ACO cost ($/h) [40]	CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3				
1	140	48	40	50	8529	7250	7153	7153
2	150	51	40	50	8648	7511	7203	7203
3	155	56	40	50	8675	7704	7278	7278
4	160	54	41	51	8795	7742	7280	7285
5	165	63	44	50	8758	8211	7545	7545
6	170	64	48	51	8848	8459	7723	7679
7	175	62	42	50	8964	8406	7457	7457
8	180	47	40	50	9308	7923	7138	7138
9	210	65	50	51	9609	9040	7731	7731
10	230	67	52	54	10,049	9599	7920	7937
11	240	74	68	77	11,520	11,184	9231	9231
12	250	76	71	80	12,098	11,616	9470	9470
13	240	70	59	65	10,676	10,320	8482	8482
14	220	68	57	58	9982	9707	8186	8186
15	200	68	55	59	9569	9351	8154	8159
16	180	64	46	52	9030	8469	7622	7626
17	170	62	44	50	8872	8189	7526	7525
18	185	68	55	57	9273	9061	8132	8131
19	200	71	61	67	9990	9852	8652	8636
20	240	77	75	86	12,646	11,897	9846	9811
21	225	75	70	79	11,496	11,101	9383	9383
22	190	69	58	62	9534	9488	8371	8370
23	160	63	46	50	8667	8077	7572	7572
24	145	54	41	50	8517	7498	7254	7262
Total	4580	1536	1243	1399	232,053	217,655	192,309	192,250

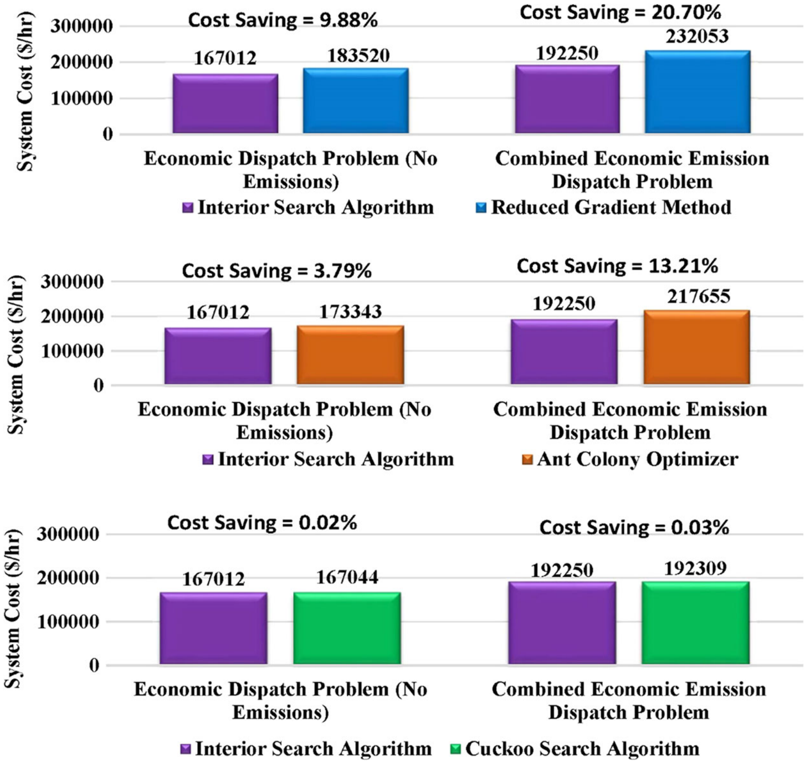


Fig. 3 Comparison of ISA versus other techniques

Table 9 All sources without wind energy

Time (h)	PD (MW)	Generation (MW)			RGM cost ($/h) [51]	ACO cost ($/h) [51]	CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3				
1	140	48	40	50	6298	6152	6157	6122
2	150	60	40	50	6483	6380	6393	6392
3	155	63	43	50	6579	6496	6509	6539
4	160	63	47	50	6677	6611	6624	6623
5	165	65	49	50	6778	6727	6741	6741
6	170	66	52	52	6881	6844	6856	6849
7	175	66	51	52	6950	6924	6827	6827
8	180	65	49	50	7020	6972	6714	6713
9	210	68	56	60	7626	7616	7226	7204
10	230	70	57	61	8001	7987	7336	7286
11	240	78	72	83	8498	8469	8334	8346
12	250	78	78	90	8808	8719	8669	8669
13	240	72	65	71	8277	8272	7747	7746
14	220	71	59	63	7831	7827	7396	7396
15	200	69	58	62	7485	7479	7319	7319
16	180	67	53	55	7074	7048	6963	6964
17	170	64	47	50	6833	6769	6635	6635
18	185	68	56	58	7202	7187	7150	7151
19	200	71	62	67	7548	7549	7556	7555
20	240	78	75	87	8569	8513	8514	8513
21	225	75	71	79	8168	8148	8151	8161
22	190	70	58	62	7316	7313	7321	7321
23	160	64	45	50	6677	6611	6625	6625
24	145	56	41	50	6387	6266	6275	6311
Total	4580	1615	1324	1452	175,966	174,879	172,038	172,008

24-hour generation cost for ED case in comparative study clearly proves that lowest cost is obtained with ISA compared to other techniques.

6.2.2 *With emission (CEED)*

Table 10 shows results of cost and generation of 24 h for the case when all sources without including wind energy. This table also shows comparative study of generation cost obtained from CSA and ISA with respect to prior solved techniques RGM and ACO. Statistically aggregated 24-hour generation cost for CEED case in comparative study clearly proves that lowest cost is obtained with ISA compared to other techniques.

Figure 4 shows the comparison of cost saving of ED and CEED using ISA with different algorithms like RGM, ACO and CSA. Aggregated cost saving for all sources without including wind energy of ISA with respect to RGM, ACO and CSA is 18.52, 13.25 and 0.03%, respectively.

6.3 All sources without solar and wind energy

6.3.1 *Without emission (ED)*

Table 11 shows results of cost and generation of 24 h for the case when all sources without including solar and wind energy. This table also shows comparative study of generation cost obtained from CSA and ISA with respect to prior solved techniques RGM and ACO. Statistically aggregated 24-hour generation cost for ELD case in comparative study clearly proves that lowest cost is obtained with ISA compared to other techniques.

6.3.2 *With emission (CEED)*

Table 12 shows results of cost and generation of 24 h for the case when all sources without including solar and wind energy. This table also shows comparative study of generation cost obtained from CSA and ISA with respect to prior solved techniques RGM and ACO. Statistically

Table 10 All sources without wind energy

Time (h)	PD (MW)	Generation (MW)			RGM cost ($/h) [51]	ACO cost ($/h) [51]	CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3				
1	140	48	40	50	8490	7317	7179	7156
2	150	60	40	50	8528	7694	7365	7364
3	155	63	43	50	8592	7922	7479	7508
4	160	63	47	50	8675	8117	7598	7599
5	165	65	49	50	8756	8318	7721	7721
6	170	66	52	52	8878	8600	7848	7841
7	175	66	51	52	8849	8589	7816	7816
8	180	65	49	50	8969	8559	7692	7692
9	210	68	56	60	9788	9630	8269	8244
10	230	70	57	61	10,235	10,139	8397	8337
11	240	78	72	83	12,153	11,648	9620	9634
12	250	78	78	90	13,327	12,336	10,052	10,053
13	240	72	65	71	10,957	10,788	8887	8887
14	220	71	59	63	10,153	10,012	8467	8467
15	200	69	58	62	9707	9617	8377	8378
16	180	67	53	55	9093	8829	7974	7970
17	170	64	47	50	8810	8279	7608	7608
18	185	68	56	58	9340	9137	8182	8182
19	200	71	62	67	10,009	9937	8657	8657
20	240	78	75	87	12,664	12,032	9851	9849
21	225	75	71	79	11,495	11,197	9388	9400
22	190	70	58	62	9540	9479	8379	8379
23	160	64	45	50	8675	8117	7598	7596
24	145	56	41	50	8515	7491	7264	7263
Total	4580	1615	1324	1452	234,198	223,784	197,668	197,601

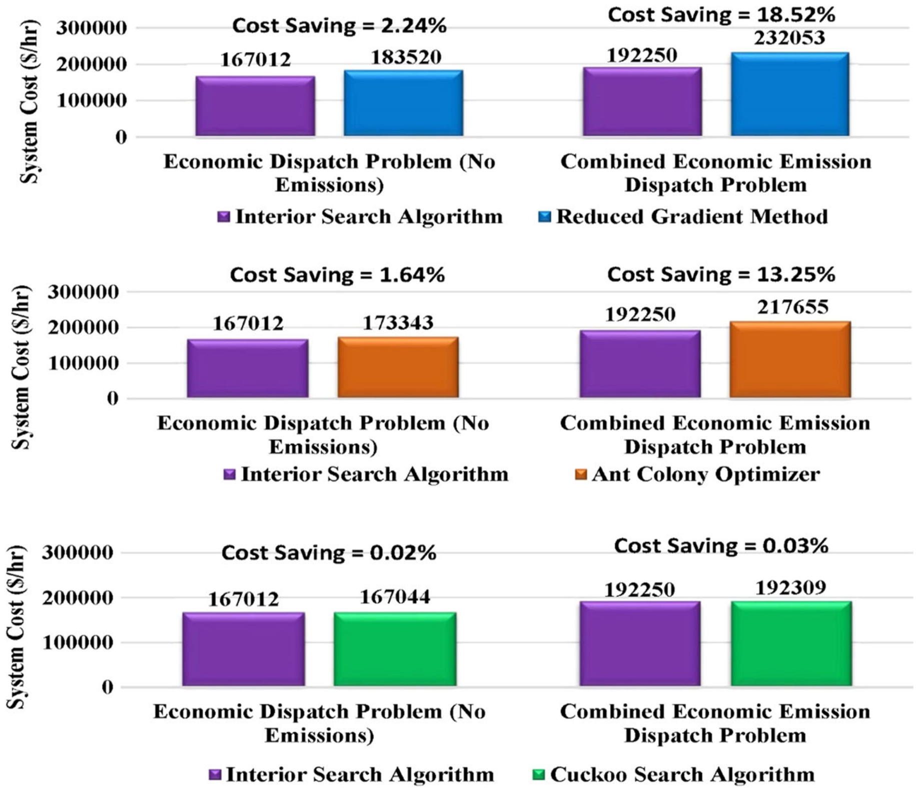


Fig. 4 Comparison of ISA versus other techniques

Table 11 All sources without solar and wind energy

Time (h)	PD (MW)	Generation (MW)			RGM cost ($/h) [50]	ACO cost ($/h) [50]	CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3				
1	140	50	40	50	6298	6152	6157	6157
2	150	60	40	50	6483	6380	6393	6395
3	155	64	42	50	6579	6496	6509	6531
4	160	64	46	50	6677	6611	6625	6635
5	165	65	50	50	6778	6727	6741	6742
6	170	66	51	53	6881	6844	6856	6858
7	175	67	52	56	6986	6969	6973	6971
8	180	67	55	58	7094	7078	7088	7087
9	210	73	65	72	7795	7788	7793	7793
10	230	76	72	82	8300	8284	8272	8272
11	240	77	75	88	8569	8513	8514	8514
12	250	80	78	92	8848	8760	8758	8758
13	240	78	75	85	8569	8513	8514	8433
14	220	75	68	76	8040	8031	8032	8026
15	200	71	62	67	7548	7549	7556	7571
16	180	67	55	58	7094	7078	7088	7086
17	170	66	52	52	6881	6844	6856	6856
18	185	68	57	60	7204	7194	7204	7203
19	200	71	62	67	7548	7549	7556	7555
20	240	78	76	87	8569	8513	8514	8511
21	225	75	70	80	8168	8149	8152	8151
22	190	70	59	61	7316	7313	7319	7322
23	160	64	46	50	6677	6611	6625	6625
24	145	55	40	50	6389	6266	6275	6268
Total	4580	1647	1388	1544	177,291	176,212	176,370	176,320

aggregated 24-hour generation cost for CEED case in comparative study clearly proves that lowest cost is obtained with ISA compared to other techniques.

Figure 5 shows the comparison of cost saving of ED and CEED using ISA with different algorithms like RGM, ACO and CSA. Aggregated 24-hour cost saving for all sources without including solar and wind energy of ISA with respect to RGM, ACO and CSA is 15.8, 11.78 and 0.04%, respectively.

6.4 All sources without solar energy

6.4.1 Without emission (ED)

Table 13 shows results of cost and generation of 24 h for the case when all sources without including solar energy. This table also shows comparative study of generation cost obtained from CSA and ISA. Statistically aggregated 24-hour generation cost for ED case in comparative study clearly proves that lowest cost is obtained with ISA compared to CSA.

6.4.2 With emission (CEED)

Table 14 shows results of cost and generation of 24 h for the case when all sources without including solar energy. This table also shows comparative study of generation cost obtained from CSA and ISA. Statistically aggregated 24-hour generation cost for CEED case in comparative study clearly proves that lowest cost is obtained with ISA compared to CSA.

Figure 6 shows aggregated 24-hour cost saving for all sources without including solar energy of ISA with respect to CSA is 0.02%, respectively.

As shown in Fig. 7, total CEED cost using interior search algorithm for four different cases like all sources included, all sources except solar and wind, all sources

Table 12 All sources without solar and wind energy

Time (h)	PD (MW)	Generation (MW)			RGM cost ($/h) [51]	ACO cost ($/h) [51]	CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3				
1	140	50	40	50	8490	7317	7179	7179
2	150	60	40	50	8528	7694	7365	7367
3	155	64	42	50	8592	7922	7479	7499
4	160	64	46	50	8675	8117	7598	7608
5	165	65	50	50	8756	8318	7721	7722
6	170	66	51	53	8878	8600	7849	7851
7	175	67	52	56	9005	8768	7978	7978
8	180	67	55	58	9167	8998	8110	8110
9	210	73	65	72	10,527	10,406	8943	8943
10	230	76	72	82	11,867	11,347	9540	9540
11	240	77	75	88	12,664	12,032	9851	9850
12	250	80	78	92	13,511	12,476	10,170	10,170
13	240	78	75	85	12,664	12,032	9850	9746
14	220	75	68	76	11,160	10,889	9238	9230
15	200	71	62	67	10,009	9936	8657	8675
16	180	67	55	58	9167	8998	8110	8109
17	170	66	52	52	8875	8599	7849	7849
18	185	68	57	60	9347	9186	8244	8244
19	200	71	62	67	10,009	9936	8657	8657
20	240	78	76	87	12,664	12,032	9851	9847
21	225	75	70	80	11,495	11,197	9388	9388
22	190	70	59	61	9540	9479	8377	8379
23	160	64	46	50	8675	8117	7598	7598
24	145	55	40	50	8515	7491	7265	7260
Total	4580	1647	1388	1544	240,780	229,887	202,867	202,799

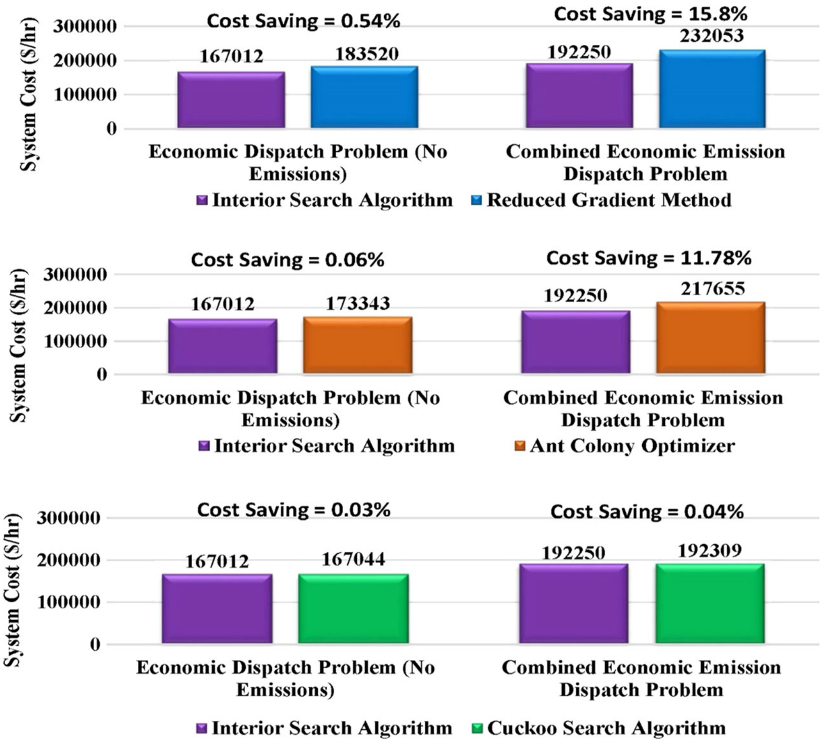


Fig. 5 Comparison of ISA versus other techniques

Table 13 All sources without solar energy

Time (h)	PD (MW)	Generation (MW)			CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3		
1	140	48	40	50	6117	6117
2	150	51	40	50	6192	6187
3	155	56	40	50	6292	6292
4	160	53	40	50	6236	6236
5	165	62	45	50	6573	6572
6	170	65	49	51	6743	6742
7	175	64	47	50	6633	6632
8	180	61	42	50	6473	6472
9	210	69	58	62	7307	7307
10	230	73	66	73	7844	7844
11	240	76	71	81	8205	8209
12	250	76	72	83	8305	8304
13	240	76	69	81	8167	8167
14	220	72	65	73	7785	7783
15	200	70	58	63	7362	7362
16	180	66	51	50	6771	6776
17	170	65	50	51	6777	6777
18	185	69	56	59	7161	7161
19	200	71	61	67	7538	7545
20	240	78	74	88	8510	8508
21	225	76	69	80	8148	8148
22	190	69	57	62	7314	7272
23	160	64	45	50	6600	6600
24	145	54	40	50	6261	6261
Total	4580	1584	1305	1474	171,314	171,274

Table 14 All sources without solar energy

Time (h)	PD (MW)	Generation (MW)			CSA cost ($/h)	ISA cost ($/h)
		G1	G2	G3		
1	140	48	40	50	7153	7152
2	150	51	40	50	7203	7199
3	155	56	40	50	7279	7279
4	160	53	40	50	7235	7235
5	165	62	45	50	7544	7545
6	170	65	49	51	7724	7724
7	175	64	47	50	7606	7606
8	180	61	42	50	7443	7443
9	210	69	58	62	8364	8364
10	230	73	66	73	9006	9006
11	240	76	71	81	9454	9461
12	250	76	72	83	9581	9581
13	240	76	69	81	9408	9407
14	220	72	65	73	8933	8933
15	200	70	58	63	8427	8427
16	180	66	51	50	7756	7758
17	170	65	50	51	7761	7761
18	185	69	56	59	8194	8193
19	200	71	61	67	8636	8644
20	240	78	74	88	9845	9842
21	225	76	69	80	9383	9383
22	190	69	57	62	8371	8325
23	160	64	45	50	7572	7571
24	145	54	40	50	7254	7254
Total	4580	1584	1305	1474	197,132	197,093

except wind energy and all sources except solar energy. Figure 7 shows that all sources included scenarios cost to be minimum compared to other scenarios.

7 Conclusion

The key objective of this work is to solve the Economic Load Dispatch (ELD) and Combined Economic Emission Dispatch (CEED) problem to obtain optimal system cost in isolated microgrid mode. The minimization of total ELD cost and total CEED cost is obtained with four different scenarios like all sources included, all sources without solar energy, all sources without wind energy and all sources without solar and wind energy. In the above scenarios, the result of ELD and CEED cost is calculated with Interior Search Algorithm (ISA) and compared with Reduced Gradient Method (RGM), Ant Colony Optimization (ACO) technique and Cuckoo Search Algorithm (CSA) considering two different cases with and without emission. The results obtained to ISA give comparatively better cost reduction as compared with RGM, ACO and CSA which

Fig. 6 Comparison of ISA versus cuckoo search algorithm

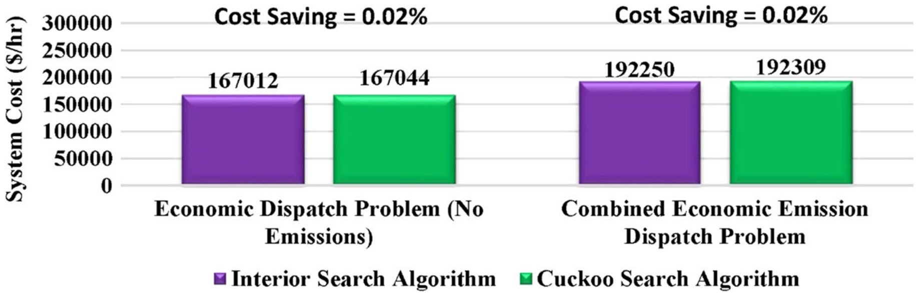
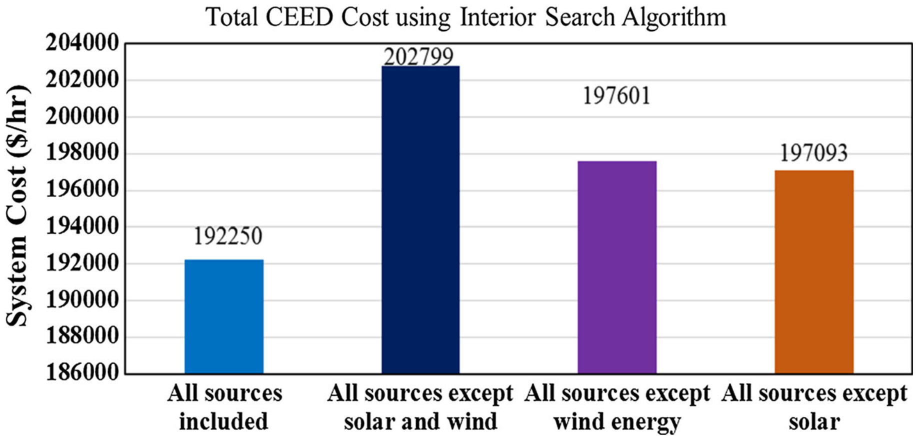


Fig. 7 Total CEED cost using interior search algorithm



shows the effectiveness of the given algorithm. The future work includes the grid-connected mode CEED problem optimization and also in the microgrid optimization of energy, achieves maximum reliability and efficiency.

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