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Multiobjective Electrical Power Dispatch of Thermal Units with Convex and Non-Convex Fuel Cost Functions for 24 Hours Load Demands

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***Abstract:** There are a host of difficult issues with scheduling, operation, and control of integrated power systems. The electricity sector is changing rapidly, and one of the most important concerns is deciding operational strategies to meet electricity demand. It is a greater challenge to satisfy customer demand for power at a minimum cost. The operating characteristics of all generators may be different. In general, operating cost is not proportionate to the performance of these generators. Therefore challenge for power utilities to balance the total load between generators. For a specific load condition on energy systems, Economic Dispatch(ED) seeks to reduce the fuel costs of power generation units. Moreover, energy utilities have also an important task to reduce gaseous emission. So the ED problem can be recognized as a complicated multi-objective optimization problem (MOOP) with two competing targets, the minimal cost of fuel and the minimum emissions effects. This paper presented an efficient method, hybrid of particle swarm optimization (PSO) and a learning-based optimization (TLBO) for combined environmental issues because of gaseous emission and economic dispatch (CEED) problems. The results were shown and verified by PSO and TLBO for standard 3 and 6-generator frameworks with combined issues of emission and economic dispatch taking into account line losses and prohibited zones (POZs) on hourly demand for 24 hours.*

***Keyword:** economic, emission, CEED, PSO, TLBO, PSO_TLBO*

I. INTRODUCTION

Electrical power systems are among the most complicated industrial systems of today's civilization that play a key position in the functioning of contemporary societies. To play this role, electrical power production and distribution must be achieved in an environmentally friendly, cost-effective and reliable manner. The continuing challenge of electrical engineers around the world is to produce, transmit and distribute electricity efficiently. One of the primary goals of the operations and planning project is the lowest possible cost for power demand. The security of individuals and equipment is a more crucial goal. In addition, as a result of the increased number of power plants, minimizing the environmental impact of power generation becomes extremely important.

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The major share of the global electric energy is produced by thermal plants that consume fossil fuels. Heat energy is released from such plants and converted to electricity generation as a mechanical form of energy.
This transformation is carried out via thermal cycles with conversion efficiencies of less than forty percent. It increases the consumption of fuel and decreases the resources that exist. In contrast, the steadily growing worldwide demand for electricity accelerates the depletion of fuel supplies.

Electricity from conventional sources such as oil, natural gas, and coal are the major source of gaseous emissions and contaminants. The question of emission impacts and air pollution in connection with electricity generation has become critical for today's operational procedure in the power system. A large proportion of the total air pollutants and gaseous emissions in the environment are produced from fossil fuel consumption in power generating plants. The negative effects of the various contaminants, including CO carbon mono oxide, CO_2 carbon dioxide, SO sulphur oxide, SO_2 sulphur dioxide NOx nitrogen oxides, Mercury, Cadmium and Lead are of great concern to the public, and cannot be excluded from organizational and preparation approaches. Strict environmental regulations and strong limits on the power generation industry have been implemented globally to minimize this impact on human lives and the atmosphere.

Practically, power losses are estimated to be between 5 percent and 10 percent of the total generation of electricity, Conejo et al. [1] and Wang et al. [2]. The economic dispatch (ED) problem is approached using conventionally designed techniques with a linear differentiable quadratic objective function. The true input-output characteristics include higher nonlinearity and irregularity due to the valve point (VP) effects, which results in non-convex non-linear fuel cost-effectiveness. To show the VP effects a sinusoidal term is added in the conventional fuel cost function, Attavir et al. [3] and Wong et al. [4]. The functions of fuel cost generators are continuously nonlinear and are discontinuous because of prohibited operating zones (POZs). The effect prohibited operating zones is formulated as inequality constraints which are described in Lee et al. [5] and Gaing et al. [6]. Currently the growing concern about the environmental problem due to air pollution Therefore, this research modifies the classical ED problem as CEED to solve the two problems. Two objectives are considered with respect to the CEED problem, namely minimizing fuel costs with a valve loading effect and minimizing emission.

With minimization of fuel cost and emission, three constraints are also considered during the analysis, namely power balance, capacities limit, and POZs. For dynamic economic emission dispatch , the ramp-rate limit constraint is taken into account together with the above three CEED problem constraints.

Tsay et al. [9] proposed an interactive approach based on Evolutionary programming (EP) to solve CEED problem of cogeneration systems. Kumarappan et al. [10] proposed a back-propagation neural network to solve the optimal economic-emission dispatch for thermal generation systems using cost penalty factor. The paper focused on the only gaseous pollution being nitrogen oxide, as this is the world's main concern.

Venkatesh et al. [11] presented a comparative approach to the issue of the economic dispatch between the EP and two GA-driven approaches. Three algorithms were applied to solve the problem, taking account of the lines flow which was determined using the Newton-Raphson method, while a cost penalty factor was applied to convert the multiobjective in one single function. Chen et al. [12] proposed an approach based integrated neural network to solve the multiobjective CEED problem.

Kumarappan et al. [13] proposed a hybrid method of GA and Tabu search technique to solve the CEED of all-thermal generation system. The objective of the author to combine the two algorithms was to minimize the probability of local minimal trapping and to boost the convergence features of the hybrid algorithm. Kar et al. [14] presented a feed-forward back-propagation neural network to solve the CEED problem. The network was trained using the results of the Lagrangian multiplier technique used initially to resolve the problem.

Brar et al. [15] proposed a Fuzzy set theory to solve CEED problem. A third objective, the security index was regarded as a multi-objective optimization (MOP) problem, as well as cost and emission minimization. Guerrero et al. [16] proposed a Differential Evolution (DE) algorithm Inspired by natural evolution to solve the CEED problem.

King et al. [17] proposed a modified h-factor to solve the CEED problem and the results obtained from PSO to CEED were compare with GA and EP. This h-factor is also known as price penalty factor. The final result shows that PSO was better Than GA and EP for the CEED. Chiang et al. [18] presented an improved GA provided with direction operator and an effective migration operation. A multiplier updating technique was used to prevent the deformation of the augmented Lagrange function. The MOP problem for economic emissions was formulated with the ε-restriction technique to produce optimal Pareto solutions.

Wang et al. [19] proposed a fuzzified multi-objective PSO algorithm to explain the CEED problem. Bharathi et al. [20] presented a comparative study on the application GA and ant colony search algorithms to explain the CEED problem. Prasanna et al. [21] presented a fuzzy mutated EP algorithm to solve the CEED. To prevent premature convergence, fuzzy set theory provides an adaptive scaling factor in the mutation process.

Wang et al. [22] proposed an improved PSO method to deal with the economic load dispatch while simultaneously considering the emission impact. Hemamalini et al. [23] presented a PSO technique to solve CEED problem considering the non-smoothness caused by the valve-point effects of the thermal generating units. Peng et al. [24] presented a DE algorithm based on a Pareto non-dominant sorting technique to solve CEED problem.

Abido et al. [25] presented a modified multi objective PSO to solve CEED optimization problem. The proposed approach provides a multi-objective variant of traditional PSO and uses its usefulness to address problems of multi-objective optimization. Jinchao et al. [26] proposed Rough sets (RS) method and an improved PSO to solve Environmental/economic/reliability Power Dispatch (EERD) problem. Krishna et al. [27] presented an analysis with their highlights, specific features and disadvantages on the current ED optimization techniques for power systems. Moreover, emissions of several pollutants are very harmful in ED techniques, thereby preventing emissions by the research a better technical approach, known as the Combined Economic Emission Dispatch (CEED).

Niknam et al. [28] presented a modified PSO technique for the optimal power flow (OPF) problem. The presented method considers the cost, power loss, and environmental impact, voltage stability as the objective functions. Hooshmand et al. [29] presented a new approach to solve the ED problem. The presented technique considers the spinning reserve and emission costs as the objective functions. Gupta et al. [30] presented PSO method to solve the CEED problem. The price of fuel and emissions are combined with a difference weighting factor in a single function. The main advantage of PSO over other modern heuristics is the simplicity modeling, secure and fast convergence, which gives less computer time than other heuristic methods. Pazheri et al. [31] presented CEED problem with non-convention electrical energy sources and electrical power storage devices. To show the advantages of non-convention sources and energy storage devices and to reduce the emission MATLAB simulations are carried out on IEEE-30 bus data with 6-generators.

Pazheri et al. [32] proposed a multi-objective optimization to solve CEED. The simulation of MATLAB is done using the sequential quadratic algorithm. The analysis showed that renewable energy plants ' electricity costs are smaller than conventional fuel-based plants. ElDesouky et al. [33] provided an optimized dispatch model with security, economics, and environmental considerations. The feasibility of using a PSO method to solve the DEED problem is evaluated using a weighted aggregation technique to achieve a global solution. Krishna et al. [34] presented a Modified Ant Colony Optimization algorithm (MACO) to solve CEED. Chandrasekarana et al., 2014 [35] presented a multi-objective cuckoo search algorithm (CSA) to solve CEED problem. A third objective, the reliability index was regarded as a MOP problem. Khan et al. [36] proposed PSO to solve CEED problem for a system with solar PV plants. Two case studies have been reviewed using PSO as an optimization method with six thermal systems and 13 solar plants. In the first case static CEED problem is solved for maximum and decreased solar radiation and dynamic CEED problem is solved for maximum radiation only with constraints of power generator limits and power balance Nevertheless, in the case of dynamic CEED, the ramp rate limits were considered.

"Table-I" shows the load characteristics for 24 hours on hourly basis. The maximum demand in 24 hours load is 1150 MW and minimum demand is 650 MW. From the table it is seen that load is changing on hourly basis and the load may increase or decrease in next hour. It is better to schedule for 24 hours onetime rather than scheduling of each hour separately for the more optimal economic and emission operation of the thermal units with convex and nonconvex fuel cost functions in power system. Nonconvex fuel cost unit operation is more practical as compare to convex fuel cost unit operation of thermal units in power system.

Load Characteristics:

Table-I: 24 hours hourly basis load demands [8]

Hour	P_D(MW)
h1	750
h2	780
h3	700
h4	650
h5	670
h6	800
h7	950
h8	1010
h9	1090
h10	1080
h11	1100
h12	1150
h13	1110
h14	1030
h15	1010
h16	1060
h17	1050
h18	1120
h19	1070
h20	1050
h21	910
h22	860
h23	850
h24	800

II. OPTIMIZATION TECHNIQUES

(A) Particle Swarm Optimization Technique (Pso):

Eberhart and Kennedy developed PSO (1995) for the first time and is a population-based optimization algorithm. The population is referred to as "swarm." Each possible solution is known as the particle. Each particle has a random velocity moving randomly in solution space in order to achieve the optimum position. All particles track their former best position in their memory, called best, and corresponding fitness. Pbest's best value is called gbest. Here gbest, is best position that swarm has discovered. If any particle finds a better solution, then all other particles try to move near to that solution. Mathematical equations are the following based on the PSO concept for the search:

Equation to update the velocity of each particle:

$$v_i^{n+1} = \omega^n v_i^n + a_1 m_1 \left(pbest_i^n - p_i^n \right) + a_2 m_2 \left(gbest_i^n - p_i^n \right) \quad (1)$$

Equation to update the position of each particle:

$$p_i^n = p_i^{n+1} + v_i^n \quad (2)$$

Where v_i^n, v_i^{n+1} are the velocities of ith particle at iteration n_{th} and $n+1_{th}$; $pbest_i^n$ is ith particle best position at iteration n; ω_i^n is weight of inertia at iteration n $gbest_i^n$ is global best position at iteration n ; p_i^n is the ith particle position at iteration k.; a_1 and a_2 are acceleration coefficients; m_1 and m_2 are random numbers between (0, 1).

Equation to update the inertia weight:

$$\omega^n = \omega_h - \frac{\omega_h - \omega_l}{iter_{\max}} \times iter \quad (3)$$

ω_h and ω_l are highest and lowest value of inertia weight and itr_{max} is maximum iteration number.

(B) Teaching learning optimization (tlbo):

TLBO algorithm was developed by Rao et al. [31] as an efficient population-based algorithm. The algorithm reflects the instructor's teaching and student's learning capabilities in a classroom. In this process, a population is considered to be a group of students in a class. The best solution so far is similar to the instructor in TLBO since the instructor is regarded as the best-learned person in society. The TLBO system is divided into two phase. The first phase is the "instructor Phase" and the second phase is the "student Phase." The 'instructor phase ' means to learn from the instructor and the 'student phase ' is to learn through interaction. Mean of a class with the P learner is expressed as:

$$x_{mean} = 1/P\left(\sum_{i=1}^{P} x_i\right) \quad (4)$$

Equation to update student's position:

$$x_{i,new} = x_{i,old} + rand.\left(x_{instructor} - T_F . x_{mean}\right) \quad (5)$$

A student interacts randomly with other students to increase their performance. Student x_i chooses another student x_j on a random basis and can express the following equation:

$$x_{i,new} = \begin{cases} x_i^{old} + rand.(x_i - x_j), \ldots\ldots f(x_i) \le f(x_j) \\ x_i^{old} - rand.(x_j - x_i), \ldots\ldots f(x_i) > f(x_j) \end{cases} \quad (6)$$

(C) hybrid pso-tlbo optimization technique:

The PSO and TLBO principles are used to propose the hybrid PSO_TLBO. Initially generate the population as per problem and calculate the fitness of each population and set the best of pbest as gbest.

In the next step apply instructor phase and update the population for best fitness. After instructor phase, apply PSO to update pbest and gbest. In the last step apply student phase of TLBO. The hybrid PSO_TLBO improves as compared to the PSO and the TLBO test because population update first in instructor phase then by PSO in last learner phase of TLBO.

III. CEED PROBLEM DESCRIPTION

The primary objective of the combined emission economic dispatch of a thermal power system is to minimise the cost as well as reduce the gaseous emission. CEED is a multi-objective problem of emission and economic optimization. The CEED problem can be described as:

$$\text{Min } obj = \sum_{t=1}^{T}\sum_{i=1}^{N}\left(f_{it}(P_{it}) + E_{it}(P_{it})\right) \quad (7)$$

Fuel cost curves are without and with valve point effect are shown in "(8)" and "(9)"

B) Economic Dispatch

(i) Without valve point effect

$$f = \sum_{t=1}^{T}\sum_{i=1}^{N} a_i + b_i P_{it} + C_i P_{it}^2 \quad (8)$$

(ii) With valve point effect

$$f = \sum_{t=1}^{T}\sum_{i=1}^{N} a_i + b_i P_{it} + c_i P_{it}^2 + \left| e_i * \sin\left(f_i * \left(P_i^{\min} - P_{it}\right)\right)\right| \$/h \quad (9)$$

Where:

a_i, b_i, c_i ei, fi : i_{th} generating unit fuel cost coefficients .

Pi^{min}= minimum generated power by the unit ith

Pit: generated power by the i_{th} unit in scheduled period t.

N: total number of thermal units.

T= total time

B) Emission Dispatch

$$E = \sum_{t=1}^{T}\sum_{i=1}^{N}\left(\alpha_i + \beta_i P_{it} + \gamma_i P_{it}^2 + n_i \exp\left(\delta_i P_{it}\right)\right) kg/h \quad (10)$$

α_i, βi,,γ_i,η_j,δ_i are ith thermal unit's emission coefficients

Linear and non-Linear Constraints:

C) Power balance limit

$$\sum_{i=1}^{N} P_{it} - P_{Dt} - P_{Lit} = 0 \quad (11)$$

P_{Lt}:line losses in scheduled period t

P_{Dt}: Demand in schedule period t

D) Generation limits

$$P_i^{\min} \le P_{it} \le P_i^{\max} \quad (12)$$

P_i^{min} : minimum power loading limit of ith unit

P_i^{max}: maximum power loading limit by ith unit.

E) Prohibited zones Limits

As follows, the operating zones of ith can be described:

$$P_i^{\min} \le P_i \le P_{i,1}^{lower}$$
$$P_{i,k-1}^{upper} \le P_i \le P_{i,k}^{lower} \quad k = 2,3,\ldots\ldots n_i$$
$$P_{i,n_i}^{upper} \le P_i \le P_i^{\max} \quad (13)$$

Where:

n_j: Total zones of ith generation unit prohibited;

$P_{i,k}^{lower}$: Lower limit of prohibited zone of k of ith unit,

$P_{i,k-1}^{upper}$: Upper limit of prohibited zone of k-1 of ith unit.

With the introduction of the "h" cost penalty factor, the MOP function of "(7)" can be translated into a single-objective optimization problem.

$$\text{Min } obj = \sum_{t=1}^{T}\sum_{i=1}^{N}\left(f_{it}(P_{it}) + h_i E_{it}(P_{it})\right) \quad (14)$$

For convex system:

$$h_i = \frac{a_i + b_i P_{it} + c_i P_{it}^2}{\left(\alpha_i + \beta_i P_{it} + \gamma_i P_{it}^2 + n_i \exp\left(\delta_i P_{it}\right)\right)}$$

(15)

For non-convex system:

$$h_i = \frac{a_i + b_i P_{it} + c_i P_{it}^2 + \left| e_i * \sin\left(f_i * \left(P_i^{\min} - P_{it}\right)\right)\right| \$/h}{\left(\alpha_i + \beta_i P_{it} + \gamma_i P_{it}^2 + n_i \exp\left(\delta_i P_{it}\right)\right)} \quad (16)$$

Table-II: Cost coefficients and generation limits for 3-units

Parameters	UNIT-1	UNIT-2	UNIT-3
a_i	100	120	150
b_i	2.45	2.32	2.10
c_i	0.0012	0.0010	0.0015
e_i	160	180	200
f_i	0.038	0.037	0.035
Pi^{min}	20	40	50
Pi^{max}	500	500	500

Table-III: Emission coefficients for 3-units [8]

Parameters	UNIT-1	UNIT-2	UNIT-3
α_i	0.0105	0.0080	0.0120
β_i	-1.355	-0.600	-0.555
γ_i	60	45	30
η	0.4968	0.4860	0.5035
δ	0.01925	0.01694	0.01478

"(11)" to "(13)" represents the linear and non linear constraints for CEED operation and "(14)" represents the final objective for CEED operation and "(15)" and "(16)"to calculate price penalty factor.

Table –IV: Cost coefficients and power limits for 6-units [6]

Unit	c_i ($/MW²)	b_i ($/MW)	a_i ($)	P_i^{max} (MW)	P_i^{min} (MW)
1	0.0070	7.0	240	500	100
2	0.0095	10.0	200	200	50
3	0.0090	8.5	220	300	80
4	0.0090	11.0	200	150	50
5	0.0080	10.5	220	200	50
6	0.0075	12.0	190	120	50

Table –V: Emission coefficients for 6-units [6]

Units	α (lb/h)	β(lb/MW/h)	γ(lb/MW²/h)
1	13.85932	0.32767	0.00419
2	13.85932	0.32767	0.00419
3	40.26690	-0.54551	0.00683
4	40.26690	-0.54551	0.00683
5	42.89553	-0.51116	0.00461
6	42.89553	-0.51116	0.00461

Table –VI: Prohibited zones for 6-units [6]

Unit	Prohibited zones MW)	P_i^0	UPR_i	DPR_i
1	[210 240][350 380]	440	80	120
2	[90 110][140 160]	170	50	90
3	[150 170][210 240]	200	65	100
4	[80 90][110 120]	150	50	90
5	[90 110][140 150]	190	50	90
6	[75 85][100 105]	110	50	90

IV. RESULTS AND DISCUSSION

The proposed algorithm is applied on 3-units and 6-units of thermal plants for CEED problem. There cases are considered here first case for three units with valve point effects and transmission losses and second case for 6 units with line losses and third case for 6 units with prohibited zone as an additional constraint in second case. MATLAB simulation is performed on MATLAB R2010a with Intel's earlier Core Duo processor, 1.6 GHz with 3GB RAM.

Case-I: The test system-I compromised 3-thermal units with valve point effect and transmission losses. PSO parameters a1, a2=2, swarm size=50, and maximum iteration=500, minimum and maximum velocity are -0.5*Pmin and 0.5*Pmax and for TLBO; swarm size=50 and maximum iteration =500 are used for all cases. Cost coefficients, power limits is taken from "Table-II" and emission coefficient is taken from "Table-III" and loss matrix is taken from [7].

Table –VII: Comparison Result for case-I

TERMS	PSO	TLBO	PSO_TLBO
TC	128357.7	128140.3	**116583.7**
TFC	83155.5	83001.8	**75427.3**
TE	97356.3	97219.3	**91577.0**
TL	540.8	539.80	**459.0**

TC-Total Cost in $/h
TFC- Total Fuel Cost in $/h,
TE-Total Emission kg/h
TL-Total Loss in MW

Table –VIII: hourly power generated for case-I

Hour	P1 (MW)	P2 (MW)	P3 (MW)
h1	321.1	294.6	148.7
h2	268.5	212.7	310.3
h3	369.9	231.3	112.8
h4	90.2	124.9	444.9
h5	90.4	435.1	157.7
h6	225.6	294.7	292.4
h7	185.3	355.1	427.0
h8	267.6	291.0	471.9
h9	251.1	371.5	489.8
h10	425.6	296.2	382.1
h11	268.0	447.7	409.0
h12	366.5	382.7	427.0
h13	346.3	379.1	409.0
h14	446.4	224.6	381.9
h15	314.2	379.6	337.2
h16	350.4	452.0	283.3
h17	350.7	413.0	310.3
h18	350.7	412.9	382.1
h19	401.8	346.1	346.1
h20	442.7	480.4	157.7
h21	211.8	322.8	391.1
h22	269.9	294.5	310.3
h23	286.2	212.9	364.2
h24	216.4	295.0	301.4

Table –IX: hourly fuel cost, emission, losses for case-I

Hour	Fuel cost ($/h)	Emission (Kg/h)	Loss (MW)
h1	2543.1	1799.3	14.3
h2	2471.5	1900.3	11.5
h3	2522.6	2092.2	14.1
h4	2210.7	2645.1	8.0
h5	2401.4	2342.0	13.0
h6	2656.3	1892.7	12.6
h7	3127.3	3485.2	17.5
h8	3223.6	4128.3	18.5
h9	3599.3	4972.4	22.3
h10	3482.7	5538.0	23.9
h11	3567.1	4895.9	24.7
h12	3743.7	5111.2	26.1
h13	3526.5	4530.0	24.4
h14	3480.2	6272.9	22.1
h15	3319.2	3433.9	21.0
h16	3428.6	4601.8	25.6
h17	3471.7	4056.3	24.0
h18	3696.6	4705.4	25.7
h19	3701.1	4673.6	24.1
h20	3560.8	7525.6	30.7
h21	3137.1	2885.1	15.7
h22	2697.9	2245.4	14.6
h23	2795.3	2481.8	13.3
h24	2650.3	1922.5	12.5

Table-“VI” shows the result obtained from the proposed method and it compares from other methods PSO and TLBO for case-I and “Table-VII” show the optimal hourly power generation from all the three committed units and “Table-VIII” shows the hourly fuel cost, emission, and losses.

Case-II: The test system-I compromised 6-thermal units for CEED with transmission losses. Cost coefficient, power limit data is taken from “table-IV”, emission coefficients are taken from “table –V” and loss matrix is taken from [6].

Table –X: hourly power generated (P1-P3) for case-II

Hour	P1 (MW)	P2 (MW)	P3 (MW)
h1	203.5	119.7	117.5
h2	211.6	122.7	119.8
h3	192.8	111.1	108.4
h4	183.6	101.1	98.4
h5	186.3	105.3	101.9
h6	209.2	128.7	120.2
h7	246.3	159.2	145.9
h8	268.2	173.6	160.5
h9	296.6	194.5	179.3
h10	293.3	193.1	177.3
h11	301.9	196.9	180.9
h12	322.4	200.0	197.5
h13	304.3	199.9	185.4
h14	275.8	179.5	164.6
h15	269.7	173.4	160.3
h16	285.9	187.4	172.2
h17	283.0	184.6	169.5
h18	308.7	200.0	187.6
h19	290.4	189.4	174.6
h20	281.7	184.8	171.0
h21	238.8	150.2	141.6
h22	227.3	139.4	131.2
h23	222.9	138.2	130.3
h24	208.9	127.9	120.6

Table –XI: hourly power generated (P4-P6) for case-II

Hour	P4 (MW)	P5 (MW)	P6 (MW)
h1	63.3	142.2	109.5
h2	66.9	152.2	112.9
h3	57.5	136.5	98.6
h4	52.8	128.9	89.5
h5	55.2	131.3	94.6
h6	68.8	159.8	120.0
h7	87.7	200.0	120.0
h8	97.4	200.0	120.0
h9	110.2	200.0	120.0
h10	106.8	200.0	120.0
h11	111.0	200.0	120.0
h12	121.4	200.0	120.0
h13	111.3	200.0	120.0
h14	100.0	200.0	120.0
h15	96.3	200.0	120.0
h16	104.7	200.0	120.0
h17	103.0	200.0	120.0
h18	114.7	200.0	120.0
h19	105.9	200.0	120.0
h20	102.6	200.0	120.0
h21	81.7	186.0	120.0
h22	75.4	174.3	120.0
h23	74.0	172.1	120.0
h24	69.3	160.1	120.0

Table –XII: hourly fuel cost, emission, losses for case-II

Hour	Fuel Cost ($/h)	Emission (kg/h)	Loss (MW)
h1	9230.7	580.4	5.6
h2	9592.7	668.0	6.2
h3	8636.1	444.5	4.9
h4	8048.9	325.3	4.3
h5	8287.8	368.9	4.5
h6	9865.8	719.7	6.6
h7	11685.2	1297.6	9.1
h8	12394.0	1589.1	9.7
h9	13369.0	2032.5	10.6
h10	13245.7	1973.5	10.5
h11	13490.9	2092.6	10.7
h12	14100.5	2412.6	11.3
h13	13615.4	2153.5	10.9
h14	12635.3	1693.9	9.9
h15	12391.5	1589.7	9.7
h16	13000.5	1858.6	10.2
h17	12877.6	1802.9	10.1
h18	13736.9	2216.1	11.0
h19	13121.0	1915.9	10.4
h20	12878.3	1802.8	10.1
h21	11177.9	1129.9	8.3
h22	10572.7	932.9	7.5
h23	10455.9	895.0	7.4
h24	9866.2	719.6	6.7

Table –XIII: Comparison Result for case-II

TERMS	PSO	TLBO	PSO_TLBO
TC	517781.4	517741.5	**478145.4**
TFC	311044.2	31146.9	**278276.4**
TE	44437.1	44430.3	**33215.39**
TL	245.3	245.3	**206.2398**

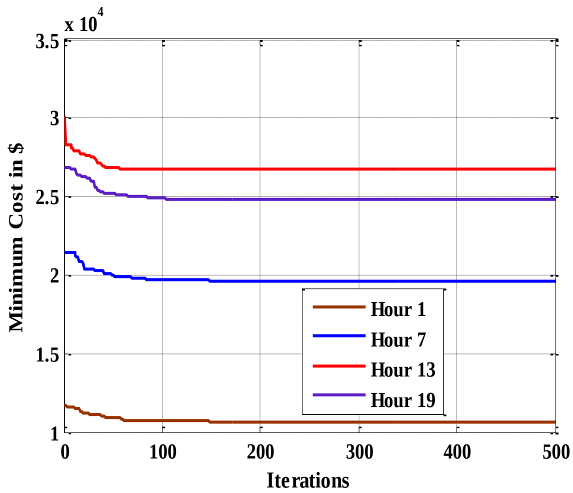

Fig.1: hourly cost variations for case-II

Case-III: The case-III compromised 6-thermal units for CEED with transmission losses and an additional constraint prohibited zones. Cost coefficient, power limit data is taken from "table-IV", emission coefficients are taken from "table –V", prohibited zone data is taken from "table-VI", and loss matrix is taken from [6] for combined economic emission dispatch of power system for 24 hours hourly load demands.

Table –XIV: hourly power generated (P1-P3) for case-III

Hour	P1 (MW)	P2 (MW)	P3 (MW)
h1	190.3	89.9	170.0
h2	240.0	114.4	111.3
h3	168.8	110.1	96.4
h4	162.0	88.7	170.0
h5	183.8	110.4	100.2
h6	177.1	110.4	170.0
h7	240.0	160.0	131.2
h8	240.9	139.8	240.0
h9	270.7	172.4	240.1
h10	380.0	136.4	170.1
h11	380.0	139.9	170.0
h12	381.3	140.0	242.6
h13	380.0	160.0	170.0
h14	268.7	189.7	174.4
h15	319.6	140.0	190.7
h16	282.5	182.8	176.9
h17	298.9	140.0	181.0
h18	380.0	160.5	240.0
h19	284.4	174.8	240.0
h20	380.0	128.8	170.0
h21	240.2	160.2	135.9
h22	240.1	137.8	126.1
h23	200.7	160.0	170.0
h24	240.0	90.0	170.0

Table –XV: hourly power generated (P4-P6) for case-III

Hour	P4 (MW)	P5 (MW)	P6 (MW)
h1	56.8	150.2	98.5
h2	60.8	139.6	120.0
h3	90.0	150.2	89.4
h4	50.0	110.1	73.1
h5	53.8	132.7	93.7
h6	120.0	129.4	98.4
h7	120.0	187.1	120.0
h8	90.2	188.8	120.0
h9	97.7	200.0	120.0
h10	120.0	183.2	100.0
h11	120.0	180.3	120.0
h12	136.4	140.0	120.0
h13	120.1	170.1	120.0
h14	107.1	200.0	99.6
h15	108.6	139.4	120.0
h16	108.0	200.0	120.0
h17	120.1	200.0	120.0
h18	90.0	185.4	74.9
h19	120.0	140.0	120.0
h20	120.0	140.0	120.0
h21	78.2	183.7	120.0
h22	90.0	172.9	99.9
h23	66.1	140.0	120.0
h24	66.5	139.7	99.7

Table –XVI: hourly fuel cost, emission, losses for case-III

Hour	Fuel Cost ($/h)	Emission (Kg/h)	Loss (MW)
h1	9203.314	687.8801	5.751541
h2	9550.918	705.3528	6.108772
h3	8722.851	466.206	4.851054
h4	7997.621	487.0264	3.915377
h5	8296.788	366.3001	4.555292
h6	9849.34	927.3376	5.27226
h7	11709.87	1338.688	8.38619
h8	12384.97	1775.179	9.640767
h9	13371.97	2136.322	10.86735
h10	13105.18	2269.818	9.754574
h11	13381.85	2312.531	10.21301
h12	13977.08	2839.215	10.27339
h13	13504.78	2358.995	10.14364
h14	12622.73	1760.386	9.536969
h15	12225.06	1809.065	8.331443
h16	12997.88	1860.619	10.2026
h17	12825.76	1869.872	9.962864
h18	13575	2657.709	10.84919
h19	13047.55	2172.515	9.161305
h20	12716.11	2166.847	8.816639
h21	11185.45	1131.371	8.281045
h22	10521.3	978.5978	7.000244
h23	10446.21	975.3923	6.784486
h24	9700.952	886.201	5.936419

Table –XVII: Comparison Result for case-III

TERMS	PSO	TLBO	PSO_TLBO
TC	546576.7	534948.8	**500020.1**
TFC	320765.4	310879.5	**276920.6**
TE	48814.3	46817.19	**36939.43**
TL	256.6	239.8915	**194.5964**

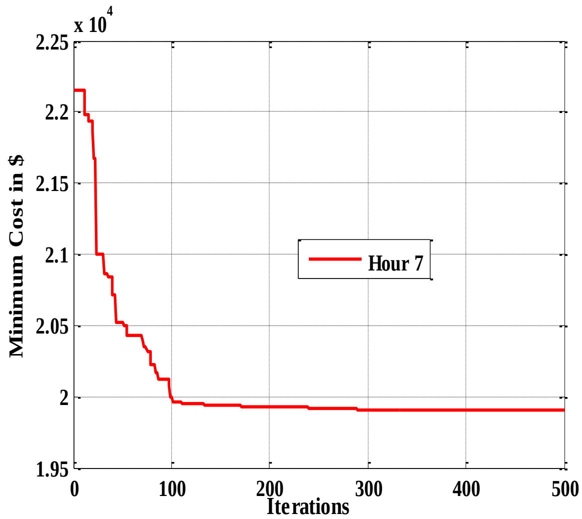

Fig.2: Variation of cost in hour-7 for case-III

Table-“XIII” shows the result obtained from the proposed method and it compares from other methods PSO and TLBO for case-II and “Table-X” show the optimal hourly power generation from three committed units (P1-P3) and “Table-XI” show the optimal hourly power generation from three committed units (P4-P6) and “Table-XII” shows the hourly fuel cost, emission, and losses for case-II. Table-“XVII” shows the result obtained from the proposed method and it compares from other methods PSO and TLBO for case-III “Table-XIV” show the optimal hourly power generation from three committed units (P1-P3) and “Table-XV” show the optimal hourly power generation from three committed units (P4-P6) and “Table-XVI” shows the hourly fuel cost, emission, and losses for case-III.

V. CONCLUSION

The paper shows an efficient and effective method based on a hybrid of PSO and TLBO for CEED problems. Three cases are considered in this paper. In the first case, three thermal units with valve point effect and line losses are considered and solved for CEED with the proposed method PSO_TLBO and result obtained from the proposed method are also verified and analysis with the PSO and TLBO methods. In the second case, six thermal units with transmission line losses are considered and solve for CEED with proposed methods. For the third case, an additional constraint prohibited zone is considered in the second case. Results obtained from the second and third cases are also verified and compared with PSO and TLBO methods as the case first. In all the cases proposed method gives better results as compare to PSO and TLBO methods but conversion time is much more as compare to PSO and TLBO methods.

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