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Economic power dispatch for an interconnected power system based on reliability indices

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ABSTRACT

Reliability indices are always one of the most important factors in the power systems. In this paper, the problem of the economic load dispatch(ELD) and the problem of combined economic emission load dispatch(CEELD) have been improved taking into account reliability indices. That is, the problem of reliability and ELD are proposed as combined economic load dispatch reliability(CELDR) and the problem of CEELD and reliability are suggested as (CEELDR). In solving CELDR and CEELDR problems, tried to use power generators in a very reliable way to save system load, as well as minimum fuel and emission costs. In this effort, the ELD of power plants is successfully implemented in a single system containing 6 generating units, taking into account the reliability and emissions of the system with and without system power loss, equality & inequality constraints,and valve point effects, by using the exchange market algorithm (EMA). The results suggest that the reliability indicators in ELD can be used to create greater reliability in providing consumers with uninterrupted power.

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1. INTRODUCTION

In this paper, the main objective is to schedule the output power of committed generating units so as to meet the required load with high reliability at minimum operating cost while satisfying system equality and inequality constraints [1, 2]. The practical ELD problem should be a non-convex problem with practical constraints, which cannot be solved directly through the mathematical optimization approaches. For example, the dynamic programming method can solve such types of problems, but it suffers from so- called the curse of dimensionality [3]. So, from the last decades, some advanced heuristic techniques such as genetic algorithm (GA) [4-6], stochastic fractal search (SFS) [7-9], particle swarm optimization (PSO) [10-12], biogeography-based optimization (BBO) [13-15], crow search algorithm (CSA) [16], symbiotic organisms search (SOS) [17], backtracking search algorithm (BSA) [18, 19], and exchange market algorithm [20, 21], are developed to solve these problems. In order to optimize the multi-object function of CELDR and CEELDR problems the EMA is applied to a system with 6 generation units.

EMA was first proposed by N. Ghorbani and E. Babaei in 2014. It's inspired by human intelligence and the process of trading shares in the stock markets. In the EMA, the market mode is available per each iteration of the program as balanced market, where the algorithm absorbs individuals toward the elite members, and oscillated market, where the algorithm is responsible for the searching process and finding unknown points. In EMA, the fitness of individuals is evaluated after each market mode, then they are ranked based on their conditions and fitness and placed in different groups by considering high capability of EMA in finding a global optimum point [21], in this paper the EMA algorithm is applied to solve CELDR and CEELDR problems.

2. PROBLEM FORMLATION

2.1. Objective function in problem

In solving CELDR&CEELDR problems, it is aimed to decrease the fuel cost of power plants along and greenhouse gases (GHGs) emission costs, and at the same time to increase the system reliability by applying system reliability in the solution process. The variables of the problem are the generated power of plants defined as follows [21]:

$$\text{Minimizing: } F = [F_{FC}, F_{GHG}, EENS] \quad (1)$$

where F_{FC} is the fuel cost of the units, F_{GHG} the greenhouse gases emission costs and EENS the expected energy not supplied. The objective function of the CELDR is consisting of two independent functions. Therefore, the objective function (1) should be replaced by the following objective function:

$$\text{Minimizing: } F = [F_{FC}, EENS] \quad (2)$$

2.2. ELD problem formulation

The aim of the ELD is minimizing the cost function of the system considering the system constraints. Generally, the simplified fuel cost function of each generation unit is as follows:

$$F_{FC} = \sum_{i=1}^{n} F_i(P_i) \quad (3)$$

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \quad (4)$$

where, F_i is the cost function of the i^{th} generation unit, F_{FC} is the total generation fuel cost, a_i, b_i and c_i are the cost coefficients of the i^{th} generation unit, n is the last generation unit number and P_i is the output power of the i^{th} generating unit. A total generated power should equal to total system demand power plus total transmission line power losses. In other words:

$$\sum_{i=1}^{n} P_i = P_{load} + P_{loss} \quad (5)$$

where P_{load} is the total system load. P_{loss} is the power loss of a transmission line, which is defined as follows using B factor:

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \quad (6)$$

In ELD problem without considering power losses. The total power should be the same as the total load as follows:

$$\sum_{i=1}^{n} P_i = P_{load} \quad (7)$$

The output power of each generation unit should correspond to the following constraint:

$$P_{i,\min} \le P_i \le P_{i,\max} \quad (8)$$

where, $P_{i,\min}$ and $P_{i,\max}$ are the minimum and maximum power amounts of i^{th} unit, respectively.

Power generation units with multi-steam valve create more variations in power unit cost function. Therefore, the cost function in (4) should become:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 + |e_i \times \sin(f_i \times (P_{i,\min} - P_i))| \quad (9)$$

where e_i and f_i are the coefficients of unit i reflecting valve-point loading [21].

2.3. Emission problem formulation

It is aimed to decrease the greenhouse gases (GHGs) emission costs of power plants. The GHGs is CO_2 in this paper. The greenhouse gas emission costs from each unit depends on the power generated by that unit, which is given in (10).

$$F_{GHG} = \sum_{i=1}^{n} h.EM_i(p_i) \tag{10}$$

$$EM_i(p_i) = ef_i(f_i + g_i p_i + h_i p_i^2) \tag{11}$$

where, $EM_i(p_i)$ is the GHGs emissions of thermal unit i . f_i, g_i *and* h_i are the fuel consumption coefficients of thermal units, ef is the fuel emission factor of GHGs for thermal generator, h is the given GHGs emission price which is determined by markets [21].

2.4. Reliability problem formulation

In calculating the system's EENS,our goal is creating a relationship between each unit forced outage rate value and amount of the productive power of that unit. In this way, we can compute the EENS of each power unit that depends on the value of forced outage rate (FOR) and production power of each unit by using the following equations:

$$EENS_i = FOR_i \times T \times P_i \quad (MWh) \tag{12}$$

$$EENS = \sum_{i=1}^{n} EENS_i \quad (MWh) \tag{13}$$

where, P_i is the i^{th} unit's power capacity in terms of MW. T is the time interval in terms of hours, n is the number of the last unit. As shown in (12) and (13) have been used to compute EENS in the power market and deregulated systems [22].

2.5. Combination of ELD, emission and reliability in objective function

Since the ELD and emission cost, and EENS in terms of ($/h) and MWh respectively, per-unit coding approaches have been used for combination multi-objective functions to a single objective function [22]. The final objective function of the CEELDR problem is as follows:

$$\min imize(F = \gamma \times F_{FC,pu} + \eta \times F_{GHG,pu} + \mu \times EENC_{pu}) \quad (pu) \tag{14}$$

where $F_{FC,pu}$ is the fuel cost in per-unit and equals:

$$F_{FC,pu} = \frac{F_{FC}}{F_{FC,\max}} \quad (pu) \tag{15}$$

$$F_{FC,\max} = \sum_{i=1}^{n} (a_i + b_i P_{i,\max} + C_i P_{i,\max}^2) \quad (\$/h) \tag{16}$$

In (14), $F_{GHG,pu}$ is the emission cost in per-unit and equals:

$$F_{GHG,pu} = \frac{F_{GHG}}{F_{GHG,\max}} \quad (pu) \tag{17}$$

$$F_{GHG,\max} = \sum_{i=1}^{n} h \times ef_i(f_i + g_i p_{i,\max} + h_i p_{i,\max}^2) \tag{18}$$

where, $EENS_{pu}$ is the per unit form of EENS and equals:

$$EENS_{pu} = \frac{EENS}{EENS_{\max}} \quad (pu) \tag{19}$$

and

$$EENS_{\max} = \sum_{i=1}^{n} FOR_i \times T \times P_{i,\max} \quad (MWh) \tag{20}$$

The parameters γ, η and μ are constants related to the influence percentage of each fuel cost, emission cost and EENS on the objective function and It is necessary to specify that the sum of these parameters is equal to one [22].

3. EXCHANGE MARKET ALGORITHM

The detailed data about the EMA that is appropriate for solving optimization problems, represented in [22]. The EMA has two searcher operators and two absorbent operators. In the EMA method there exists a specific number of shares, each member intelligently tries to buy a number of them, and intelligently performs to gain the maximum possible profit at the end of each period by calculating the validity of his own total shares. After each market mode, the members with high, middle, and lower ranks will be sorted as group 1, group 2, and group 3, respectively [22].

3.1. EMA in balanced mode

In this mode, each individual is ranked based on the number of each type of share he holds and the fitness function. After sorting population, they will be sorted as group 1, group 2, and group 3, respectively and they will be changed, as follows [22].

3.1.1. Frist group members with high ranks

The members of this group are the elite stockbrokers.

3.1.2. Second group members with mean ranks

The members of this group use the successful experiences of elite stockbrokers, and based on the (21) to get further profit.

$$pop_j^{group(2)} = r \times pop_{1,i}^{group(1)} + (1-r) \times pop_{2,i}^{group(1)}$$

$$i = 1,2,3,...,n_i \text{ and } j = 1,2,3,...,n_j \tag{21}$$

where, n_i is the n^{th} member of the first group, n_j is the n^{th} member of the second group and r is a random number in interval [0, 1]. $pop_{1,i}^{group(1)}$ and $pop_{2,i}^{group(1)}$ are the members of the first group and $pop_j^{group(2)}$ is the j^{th} member of the second group.

3.1.3. Third group members with low ranks

The members of this group get more profit would change the number of their shares based on the (22) and (23):

$$S_k = 2 \times r_1 \times \left(pop_{i,1}^{group(1)} - pop_k^{group(3)}\right) + 2 \times r_2 \times \left(pop_{i,2}^{group(1)} - pop_k^{group(3)}\right) \tag{22}$$

$$pop_k^{group(3),new} = pop_k^{group(3)} + 0.8 \times S_k \quad k = 1,2,3,...,n_k \tag{23}$$

where r_1 and r_2 are random numbers in the interval [0 1]and n_k is the n^{th} member of the third group. $pop_k^{group(3)}$ is the k^{th} member and S_k is the share variations of the k^{th} member of the third group.

3.2. EMA in oscillation mode

In this mode,the shareholders would start trading their shares.They will be sorted as a member of group1, group2, and group3, respectively,and will be changed in their shares based on the policy of the group as follows [22].

3.2.1. First group members with high ranks

The members of this group lead the stock market and to preserve their rank, they do not undergo the trade risk.

3.2.2. Second group members with mean rank

The sum of the shares held by members tends to be constant and only the number of some of each type of shares increases and some decrease in a way that the sum remains constant. The number of shares held by each member increases based on (24) [22].

$$\Delta n_{t1} = n_{t1} - \delta + \left(2 \times r \times \mu \times \eta_1\right) \tag{24}$$

$$\mu = \left(\frac{t_{pop}}{n_{pop}}\right) \tag{25}$$

$$n_{t1} = \sum_{y=1}^{n} \left|s_{ty}\right| \qquad y = 1,2,3,\cdots,n \tag{26}$$

$$\eta_1 = n_{t1} \times g_1 \tag{27}$$

$$g_1^k = g_{1,\max} - \frac{g_{1,\max} - g_{1,\min}}{iter_{\max}} \times k \tag{28}$$

where Δn_{t1} is the amount of shares should be added to some shares, n_{t1} total shares of t^{th} member before applying the share changes. δ is the information of exchange market, S_{ty} the shares of the t^{th} member, η_1 the risk level related to each member of the second group, r a random number. t_{pop} the number of the t^{th} member in the exchange market. As shown in (25), n_{pop} shows the number of the last member in the exchange market and μ a constant coefficient for each member. Each member of the second group, r is a random number. t_{pop} the number of the t^{th} member in the exchange market. As shown in (27), g_1 the common market risk amount which decreases as iteration number increases. As shown in (28), $iter_{\max}$ the last iteration number, k the number of program iteration, $g_{1,\max}$ and $g_{1,\min}$ indicate the maximum and minimum values of risk in the market, respectively and are adjustable parameters of the EMA. The Δn_{t2} of each person equals:

$$\Delta n_{t2} = n_{t2} - \delta \tag{29}$$

where Δn_{t2} is the amount of shares should be decreased from some shares and n_{t2} is the sum share amount of t^{th} member after applying the share variations.

3.2.3. Third group members with low ranks

In this group each member sells a number of shares. The shareholders of this group change some of their shares based on (30):

$$\Delta n_{t3} = \left(4 \times r_s \times \mu \times \eta_2\right) \tag{30}$$

$$r_s = \left(0.5 - rand\right) \tag{31}$$

$$\eta_2 = n_{t1} \times g_2 \tag{32}$$

$$g_2^k = g_{2,\max} - \frac{g_{2,\max} - g_{2,\min}}{iter_{\max}} \times k \tag{33}$$

where Δn_{t3} the shear amount should be added to the shares of each member, r_s a random number in the interval [-0.5 0.5] and η_2 the risk coefficient related to each member of the third group. In (33), g_2 the variable risk of the market in the third group and μ a constant coefficient for each member. $g_{2,\max}$ and $g_{2,\min}$ indicate the maximum and minimum values of risk, respectively [22].

4. IMPLEMENTATION OF EMA IN SOLVING CELDR&CEELDR PROBLRMS

The CELDR&CEELDR problems are accomplished using the EMA by taking the following steps:

a) Selecting initial values.
b) Calculating members' fitness by (14), ranking them, and sorting of shareholders in three groups.
c) Applying variations on the shares of the second group members in normal mode by (21).
d) Applying variations on the shares of the third group members by (23).
e) Recalculating shareholders' fitness by (14), ranking and sorting members in three separate groups.
f) Trading the shares of the second group members using (24) in oscillated mode.
g) Trading the shares of the third group members using (30) in oscillated mode.
h) Jumping to step 2 until the program ending criterion is satisfied.

A flowchart of the EMA's implementation for solving the above problems is shown in Figure 1.

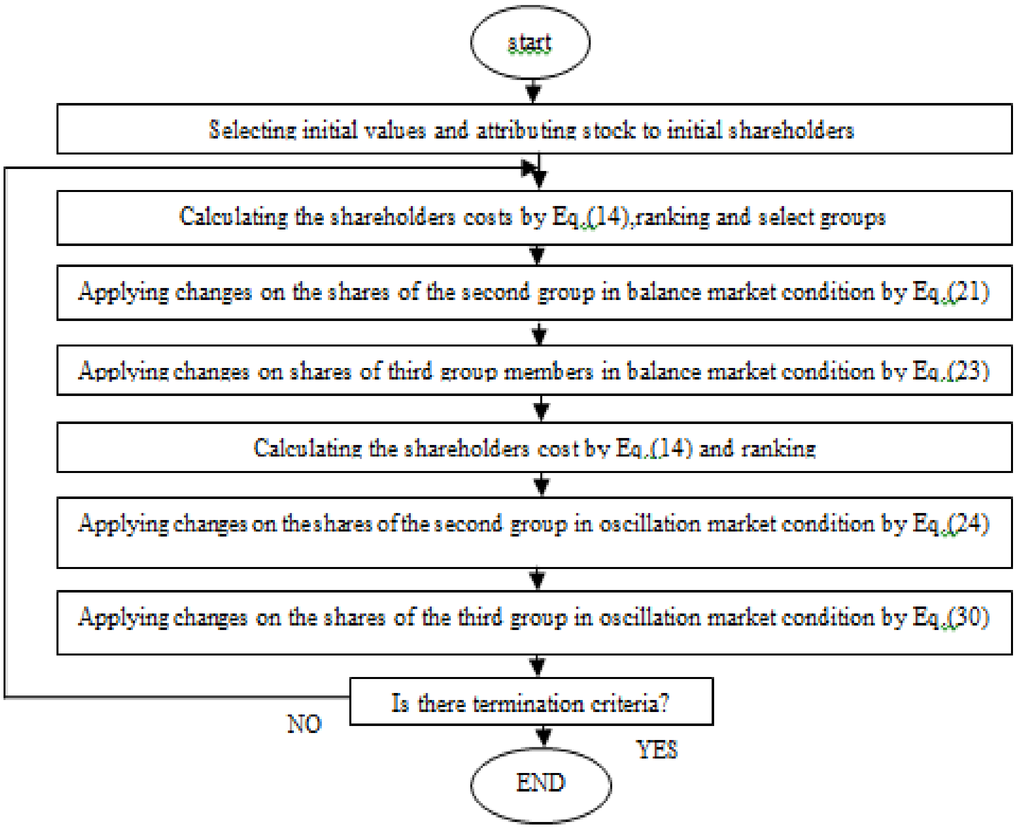

Figure 1. Flowchart of EMA for solving CELDR&CEELDR problems

5. RESULTS AND DISCUSSION

In this paper, EMA is implemented successfully in 6-units system considering ELD, emission and reliability. All the programs are developed and simulated using MATLAB version 7.01. The system configuration is Pentium IV processor with 3.2GHz speed and 2 GB RAM.The CEELDR is considered for just one hour. Fifty separate experimentations were conducted to compare the solution quality and convergence characteristics. The initial population size and iteration number are set to 100 and 5000, respectively. The objective function’s penalty factor in per unit form is set to 0.07 and in non-per-unit form is set to100. The number of individuals in 1st, 2nd and 3rd groups in non-oscillation market mode are set to 25, 25 and 50% of the initial population, and the pattern for the oscillated market mode are set to 25, 60 and 15% of initial population [22]. The necessary adjustable parameters of the proposed algorithm are risk factors of 2nd and 3rd groups in an oscillated market mode are presented in Table 1.

Table 1. Adjustable parameters of EMA for solving CEELDR problem

Risk value	g_1 [max, min]	g_2 [max, min]
6 units system	[0.1, 0.0001]	[0.005, 0.0005]

5.1. Six units system

The tests are applied to 6 generating units with power losses of transmission line, equality and inequality constraints, valve-point effects, and are solved by the EMA method. The fuel cost coefficients, generator limits, and emission data are reported in [23]. The total system load is 1200MW.

5.1.1. Solving CELDR problem considering different influence percentages of reliability

In this section, six independent experimentations are conducted considering different influence percentages of each independent function on the objective function to investigate the efficiency of CELDR problem. The *FOR* values of units in different cases (1 to 6) are presented in [24]. The experimentations are detailed as follows:

a) The aim is to reduce the unit's fuel costs, considering no reliability.
b) Decreasing the fuel cost of units by applying 20% reliability.
c) Decreasing the fuel cost of plants by applying 40% reliability.
d) Decreasing the fuel cost of plants by applying 50% reliability.
e) Decreasing the fuel cost of plants by applying 60% reliability.
f) Increasing the reliability considering no fuel cost.

The obtained results are illustrated in Table 2. In case 1, the fuel cost is 29491.4284 ($/h), which is the minimum among the other cases. The EENS by EMA method is 46.6274 MWh and is 46.6279 MWh through PSO-SIF method [24], that is the worst case in comparison with the other cases. Comparing the results of the second experimentation by EMA method that is shown in Table 2 depicts the system EENS value decreases by 0.2675 MWh and reaches to 46.3599MWh in comparing the previous case and increase the reliability percentage up to 20%.

In obtained results by EMA method, it is obvious as the reliability in the system increases, the EENS value decreases proportionally and as the fuel cost decreases, its value increases proportionally. This is accomplished in a way that as the reliability increases by 40% and the units' fuel cost decrease of 40% in the third case, the EENS value decreases in comparison with the first case by 6.9995 MWh and this value is 6.9984 MWh for PSO-SIF method.

In Figure 2 and Figure 3, the convergence characteristics of the CELDR problem objective function in per-unit form through the EMA and PSO-SIF methods are presented (case studies 1, 2 and 3). At last, in case 6, the CELDR was accomplished to decrease the optimized system's EENS considering no fuel costs. The system EENS by EMA method is 33.8997 MWh, which is the minimum among the other cases, the fuel costs by EMA method is 35725.5827$/h and is 35725.7280 for PSO-SIF method, that is the worst case in comparison with the other case studies.

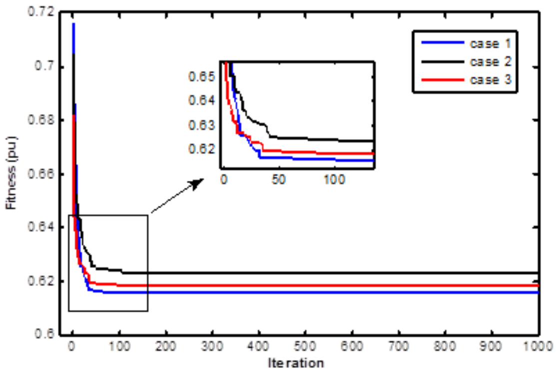

Figure 2. Convergence characteristics of the EMA for test system

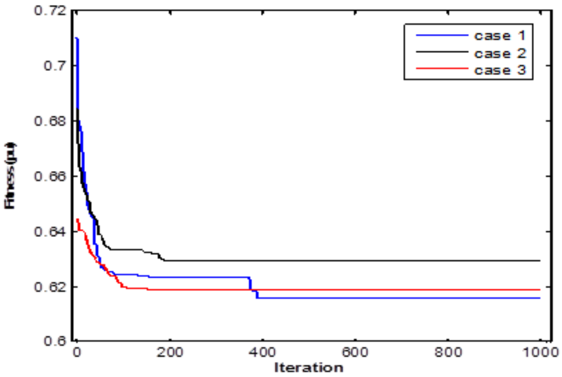

Figure 3. Convergence characteristics of the PSO-SIF for test system

5.1.2. Solving CELDR problem considering different outage rate of power units

In this section, six experimentations are conducted to investigate the influence of units' outage rate on the power amount delivered to the system. The aim is to decrease the unit fuel cost considering 50% system reliability influence on the objective function. The FOR values for B-G experimentations are shown in Table 2 and are detailed as follows:

a) The FOR values of A mode are presented in [24], and applied in all the six cases.
b) Increased FOR of unit 1 by 25% in comparison with A .
c) Decreased FOR of unit 2 by 57% in comparison with A .
d) Decreased FOR of unit 3 by 40% in comparison with A .
e) Increased FOR of unit 4 by 50% in comparison with A .
f) Increased FOR of unit 5 by 66% in comparison with A .
g) Decreased FOR of unit 6 by 50% in comparison with A .

Table 2. Results of CELDR in a system with a six - generation applying different reliability percentages

O/P	Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
	$\gamma=1.0$, $\mu=0.0$		$\gamma=0.8$, $\mu=0.2$		$\gamma=0.6$, $\mu=0.4$		$\gamma=0.5$, $\mu=0.5$		$\gamma=0.4$, $\mu=0.6$		$\gamma=0.0$, $\mu=1.0$	
	PS0_SIF [24]	EMA	PS0SIF [24]	EMA	PS0_SIF [24]	EMA	PS0_SIF [24]	EMA	PS0_SIF [24]	EMA	PS0_SIF [24]	EMA
P1	94.7998	94.7998	94.8074	94.8022	94.8044	94.7998	94.7998	94.8001	94.8000	94.7997	20.0000	20.0000
P2	100.0000	100.0000	26.9860	99.9985	99.9883	99.9998	20.0027	100.0000	99.9865	99.9998	20.0000	20.0000
P3	568.7989	568.7990	419.2013	568.7990	344.3994	344.3994	269.5996	194.7998	120.0013	119.9999	120.0000	120.0000
P4	259.5996	259.5996	508.9365	286.4000	510.6424	510.8003	515.9981	510.7998	510.8098	510.8008	519.9996	519.9999
P5	136.8015	136.8016	110.0686	110.0001	110.1652	110.0005	259.5996	259.5997	334.3979	334.9947	480.0004	479.9899
P6	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0004	40.0000	40.0000	40.0000	40.0000
F_{FC}	29491.428	29491.4284	31191.78	29534.0355	31616.91	31616.8955	32862.8637	33294.2263	34217.1802	34216.8246	35725.728	35725.5827
EENS	46.6279	46.6274	40.7776	46.3599	39.6295	39.6279	37.6800	36.6360	35.1399	35.1399	33.9000	33.8997
TP	1200	1200	1200	12000	1200	1200	1200	1200	1200	1200	1200	1200
F	0.615701	0.615701	0.627417	0.623315	0.618371	0.618362	0.607280	0.606993	0.581481	0.581450	0.475455	0.475451

The results obtained from A-G experimentations by the EMA method by comparing PSO-SIF method are shown in Table 3. In the experiment B , the FOR of unit 1 is increased by 25% in comparison with the state A . As a result, the reliability of the unit 1 is decreased. As shown in Table 3, as the FOR of unit 1 in the state B increased in comparison with state A of the same unit, the amount of delivering power in constant load of 1200 MW decreases from 94.8001MW to 20.0002MW.

As seen from Table 3, in solving this case study with the PSO-SIF method in the constant load of 1200 MW the power generation of unit 1 decreases from 94.7998MW to 57.3999MW. In solving this case, the aim is to find the minimum value of F that obtained results by EMA and PSO-SIF methods are 0.611181pu and 0.621957 pu, respectively. The results show the superiority of EMA. This results show the existence of linear relation between FOR and consequently the unit 1 reliability and the power amount delivered to the system. Therefore the total EENS of the system increases from 36.6360 MWh in A case study to 37.5840 MWh in B case. This depicts the influence of a power unit on total system EENS. And in the last. In solving case study G , the outage rate of unit 6 is decreased by 50% in comparison with that of the case A . The decreasing of outage rate results in a considerable increase in unit 6 reliability and generated power amount. As it is shown in Table 3, the generated power of unit 6 increases from 40.0004 MW in the case A to 199.9998 MW in case G . Here, the amount of EENS is decreased in comparing with case A as expected (36.6360 to 32.7586).

Table 3. CELDR problem results considering different *FOR* of power units

O/P	A		B		C		D		E		F		G	
	PSO_SIF [24]	EMA	PSO_SIF [24]	EMA	PSO_SIF [24]	EMA	PSO_SIF [24]	EMA	PSO_SIF [24]	EMA	PSO_SIF [24]	EMA	PSOSI F [24]	EMA
P1	94.7998	94.8001	57.3999	20.0002	20.0000	94.7998	94.7998	20.0000	94.7993	94.7998	94.7998	94.8022	20.0001	94.7998
P2	20.0027	100.0000	20.0021	100.0000	100.00	100.0000	20.0004	20.0001	100.0000	100.0000	100.0000	100.0000	99.9992	100.0000
P3	269.5996	194.7998	269.5996	269.5996	269.5996	120.0000	575.8662	600.0000	269.5996	269.5996	344.3994	344.3998	269.5996	120.0000
P4	515.9981	510.7998	366.3990	510.7997	409.1993	510.7999	359.3328	409.9998	409.20000	508.9349	510.7999	510.7976	508.9324	508.9324
P5	259.5996	259.5997	446.5992	259.6003	361.2009	334.3994	110.0007	110.0000	259.5993	186.6655	110.0000	110.0000	133.2403	176.2679
P6	40.0000	40.0004	40.0000	40.0000	40.0000	40.0008	40.0000	40.0000	66.8030	40.0000	40.0007	40.0002	168.2282	199.9998
F_{FC}	32862.8637	33294.2263	33531.4483	33264.7786	33435.4890	34216.8206	29716.8443	30531.8085	32565.4949	32425.5583	31616.8925	31616.8825	33706.4957	34682.2466
EENS	37.6800	36.6360	39.3760	37.5840	36.9000	33.64	28.0960	26.6000	43.5080	43.2399	41.82799	41.82799	35.32038	32.7586
TP	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
F	0.607280	0.606993	0.621957	0.611181	0.613348	0.603962	0.573768	0.571701	0.624306	0.623886	0.590923	0.590922	0.614260	0.611347

5.1.3. Solving CELDR problem considering emission cost

Tests are conducted on a system with six generation units considering fuel cost, emission cost and reliability level in 2 sections with and without considering power loss transmission. In the first section, the CEELDR problem is solved by the EMA method without considering power losses of the system and obtained results in comparing the results of the PSO-SIF method is presented in Table 4. As seen from Table 4, the aim of solving the CEELDR problem in this section is the minimization of fuel cost, emission cost, EENS, all of the system cost and minimization of all three functions. As seen from Table 4, the EMA method could find the minimum objective function (F) in per-unit form better than PSO- SIF method.

Table 4. CEELDR problem results considering fuel and emission cost and EENS

UNIT NO.	Minimization F_c		Minimization E		Minimization $EENS$		Minimization F_c , E		Minimization F_c , E , $EENS$	
	PSO-SIF [24]	EMA	PSO-SIF [24]	EMA	PSO-SIF [24]	EMA	PSO-SIF [24]	EMA	PSO-SIF [24]	EMA
Unit 1	94.7998	94.7998	20.0000	20.0000	20.0000	20.0000	20.0006	20.0000	20.0000	57.4028
Unit 2	100.0000	100.0000	20.0000	20.0000	20.0000	20.0000	20.0000	20.0000	20.0000	20.0006
Unit 3	568.7989	568.7990	120.0000	120.0000	120.0000	120.0000	344.3995	568.7989	269.5996	269.6004
Unit 4	259.5996	259.5996	520.0000	520.0000	519.9996	520.0000	515.9995	409.1988	508.9324	515.9964
Unit 5	136.8015	136.8016	479.9995	479.9999	480.0004	479.9999	259.6001	142.0022	341.4675	296.9996
Unit 6	40.0000	40.0000	40.0005	40.0000	40.0000	40.0000	40.0002	40.0000	40.0005	40.0000
Fuel cost	29491.4289	29491.4284	35725.7406	35725.7334	35725.7273	35725.7335	32853.5682	30484.4457	33733.8192	33292.0897
Emission	20227.6538	20227.65381	15064.2739	15064.2688	15064.2988	15064.2691	16456.5568	18018.2515	15971.7365	16375.3956
Total cost	49719.0828	49719.0822	50790.0145	50790.0023	50790.0261	50790.0027	49310.1250	48502.6972	49705.5557	49667.4854
EENS	46.6279	46.62798	33.9001	33.9000	33.9000	33.9000	38.4280	43.9839	37.0026	37.3060
Total power	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
F	0.653968	0.6157019	0.622537	0.622536	0.475457	0.475455	0.768560	0.678622	0.682154	0.650223

The results of solving the CEELDR problem with power loss of the system through the EMA and PSO-SIF is presented in Table 5. Data for B coefficient of power transmission losses are reported in [25]. As seen from Table 5, in solving the CEELDR problem with considering the only fuel cost or emission cost or EENS, the EMA method could find the minimum value of objective function better than PSO-SIF method that shows the high ability of the proposed EMA method.

In solving the CEELDR problem with considering all functions the obtained minimum fuel cost (29729.6280 $/h), emission cost (15223.0114$/h), system's EENS (35.00708 MWh), both fuel and emission cost (48824.3726 $/h) and minimum value of all functions (both fuel and emission cost is 49730.1020 and EENS is 38.9893 MWh) by EMA method is lower than PSO-SIF method.

The CEELDR problem with power loss of the system and considering all of the functions in the objective function is solved also by PSO-TVAC [2] & PSO [25] method and the obtained results are presented in Table 6. In this comparison, per-unit coding is used to combine proposed multi-objective problem and offer a single objective function. For PSO, C_1 and C_2 were considered equal to 2.0. The weighting inertia coefficients for both PSO and PSO-TVAC were considered a varying number in the range [0.3, 0.9] and the initial population size and iteration number were 100 and 5000, respectively. The adjustable parameters for PSO-TVAC were chosen as: C_{1i} $=C_{2f}$ =2.5 and C_{1i} $=C_{2i}$ =0.5.The adjustable parameters for PSO-SIF were chosen as: $\delta_1 = 0.04$ and $\delta_2 = 0.03$. As it is obvious from Table 6, the minimum total cost obtained using EMA is 49730.1020 ($/h) and the related EENS of which is 38.9893 (MWh) that are lower than both total cost and system's EENS obtained through PSO and PSO-TVAC approaches which shows the superiority of the EMA over the mentioned techniques.

Table 5. CEELDR problem results with power loss considering fuel and emission cost and EENS

`UNIT	Minimization F_c		Minimization E		Minimization $EENS$		Minimization F_c , E		Minimize F_c , E , $EENS$	
	EMA	PSO-SIF	EMA	PSO-SIF	EMA	PSO-SIF	EMA	PSO-SIF	EMA	PSO-SIF
Unit 1	98.2816	104.3632	20.0000	20.0000	20.0000	20.3254	20.0000	20.0000	20.0000	102.9689
Unit 2	100.0000	100.0000	20.0000	20.0000	34.4883	100.0000	20.0000	20.0000	20.0000	20.0000
Unit 3	568.8165	600.0000	134.4839	134.4847	120.0000	120.0000	568.7988	562.9216	344.3999	348.7237
Unit 4	259.5997	260.3522	520.0000	520.0000	520.0000	520.0000	455.9223	461.7216	508.9665	520.0000
Unit 5	147.3999	110.0000	500.0000	500.0000	500.0000	426.0485	110.0000	110.0000	283.0018	180.6293
Unit 6	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000
Fuel cost	29729.6280	29854.7432	36618.5159	36618.5350	36617.9183	35889..3513	30772.6508	30922.1387	33240.9395	32407.3571
Emission	20294.0312	20595.2907	15223.0114	15223.1895	15384.7880	16500.2869	18051.7218	18008.9431	16489.1625	17420.0751
TC	50023.6592	50450.0339	51841.5273	51841.5529	52002.7063	52389.6382	48824.3726	48931.0818	49730.1020	49827.4323
EENS	47.0860	47.7815	35.2241	35.2242	35.00708	35.09447	43.9583	43.7805	38.9893	39.6738
PL	14.0977	17.4154	34.4838	34.4846	34.4882	26.3739	14.7211	14.6432	16.3682	12.3221
PT	1214.0977	1214.7154	1234.4838	1234.4846	1234.4882	1226.3739	1217.7211	1214.6432	1216.3682	1212.3221
F	0.620675	0.623361	0.629096	0.629342	0.49098	0.492215	0.681797	0.685038	0.652960	0.655175
Error	0	0	0	$8.1998*10^{-4}$	0	0	0	$5*10^{-6}$	0	$5*10^{-6}$

Table 6. Comparison of the results of each method for CEELDR problem with power loss considering fuel and emission cost and EENS

Unit	Minimization F_c , E , $EENS$			
	PSO-TVAC[2]	PSO-SIF[24]	PSO [25]	EMA
Unit 1	94.5590	102.9689	110.0000	20.0000
Unit 2	98.4950	20.0000	97.3447	20.0000
Unit 3	417.6985	348.7237	195.6196	344.3999
Unit 4	267.9044	520.0000	276.7271	508.9665
Unit 5	295.5654	180.6293	403.9220	283.0018
Unit 6	41.7404	40.0000	139.5134	40.0000
Fuel cost ($/h)	31503.6376	32407.3571	34622.3139	33240.9395
Emission ($/h)	19177.1914	17420.0751	19048.1476	16489.1625
Total cost ($/h)	50680.8290	49827.4323	53670.4646	49730.1020
EENS (Mwh)	44.009273	39.6738	40.82079	38.9893
Power loss (MW)	15.962638	12.3221	23.1271	16.3682
Total power	1215.9626	1212.3221	1223.1271	1216.3682
F (pu)	0.676843	0.655175	0.697930	0.652960

6. CONCLUSION

This paper proposed the EMA to solve the CELDR&CEELDR problems. This algorithm is applied on above problems with system power loss,valve-point effect and operational constraints. The obtained results of solving CELDR &CEELDR problems by EMA method in section 5.1.1 depict the fact that the system tends to utilize power units, which have lower values of FOR or units have higher reliability considering power supplied to system. In obtained results by EMA method, it is obvious as the reliability increases,the EENS value decreases proportionally, and as the fuel cost decreases, its value increases proportionally. The obtained results of solving multi-objective CELDR and CEELDR problems by EMA method shows the high ability of proposed EMA method in compared other algorithms.

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