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Optimization of the Economic Dispatch problem by considering the emission dispatch with using the AMPSO

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ABSTRACT

In this paper, the problem of economic dispatch (ED), which is a problem with a nonlinear cost function, is solved using the proposed method. The ED problem, in addition to having a nonlinear function, also has a series of equal and unequal constraints that must be respected. Another important consideration when generating energy by power plants is, in addition to the cost, the issue of polluting the environment. In other words, in order to provide the power needed by consumers, in this issue two goals, reducing production costs and reducing the amount of emission, can be raised. This article covers all of the above issues. In this paper, an ultra-innovative algorithm is proposed to solve the problem. The proposed algorithm is based on the Particle Swarm Optimization algorithm. The proposed method is implemented on the systems under study with different conditions and the results obtained by AMPSO method are evaluated by other methods such as SA, NSGA-II and NSGA-III. The results show that the AMPSO produces optimal or nearly optimal solutions for the study systems.

1. INTRODUCTION

The use of electrical energy in most of the new equipment and technologies is increasing day by day to for control of most new features and technologies. One of the most common methods of producing electric power is the use of thermal power plants. The problem of economic dispatch (ED) reflects the amount of power produced by all power plants in certain time periods for supplying consumers with minimum production costs [1-2]. But the burning of fossil fuels, in order to provide energy, will release the polluting emissions that damage the environment. In the original ED problem, this is not the case. Due to the importance of environmental protection and the adoption of clean-cut amendments, power plants were forced to reduce emissions at a specified level [3-4].

CO_2, CO, SO_2 and NO_x can be mentioned, including gases released from burning fossils, which can directly or indirectly affect human health [5]. The issue of ED, which also addresses the reduction of pollution, is considered as the Economic Dispatch of Cost-Emission (EED) burden.

Designing and implementing a power system in accordance with the required power needs to be reliable in the supply of energy for applicants and economic performance [6-7]. As an important problem in implementing power systems, as mentioned, the optimization of the economic dispatch problem is to allocate production to generators to achieve a cost-effective solution along with reliable reliability [8-9].

There are different ways to find the right answer for the ED issue. These methods include the use of mathematical methods such as Newton's method, quadratic programming, point-and-point method for linear and nonlinear power systems [10]. But the mathematical methods used to obtain the first and second derivatives have the problem of being in the local minima. One of the other classic methods is the gradient-based method. In recent years, innovative optimization techniques have been instrumental in solving the problems of economic distribution. These methods have the ability to exit from the local minimum by using their parallel search. Among the techniques of modern optimization, we can mention the following: Genetic Algorithm (GA), memetic algorithm (MA), evolutionary programming (EP), assessment of differential (DE), Artificial Neural Network (ANN), simulated annealing (SA), Ant Colony Optimization (ACO), and Optimum Particle Swarm (PSO). The methods described in a wide range of optimization issues, which aim at most of them finding global optimizations in comparison with local optimizations, have had success [11-12].

For different issues of the economic dispatch, there are different limits, which can be balanced load with and without regard to casualties and dead regions. As well as the cost function, a second-order function can be simple or considering the effect of opening and closing fuel valves or other items. Different methods of these restrictions are considered to solve the problem of economic dispatch [13-16].

But as mentioned, another problem for energy producers is the reduction in emissions when generating energy. In other words, in the issue of economic distribution, in addition to cost, the Emission Constrained Economic Dispatch should be considered [17-27]. In this paper, both goals are considered.

To implement and solve the combined problem of two goals, one can use the conventional linear optimization methods [28], for example: the method of repeating the lambda, b) the gradient method, c) the linear programming method, and d) the Newton method. Using linear optimization methods, if solved, can accelerate and increase reliability in the response. But these methods can’t provide an adequate response to solving very complex and non-linear problems. In these methods, the multi-objective problem is transformed into a single-objective problem by using secularization methods.

But modern methods, in other words, evolutionary techniques are able to overcome problems associated with classical methods, such as the calculation of multiple targets simultaneously. The multi-purpose optimization technique, in addition to guiding the set of answers to the Pareto setup, ensures diversity and does not create a set of incorrect answers.

This paper is organized as follows. In Section 2 the economic load dispatch problem is presented and the discussion about pollution is formulated. In Section 3, the proposed algorithms are defined, and Section 4 presents the studied system. Section 5 implements the proposed algorithm on the system in different states and does a comparison and analysis of the results. Finally, Section 6 concludes the paper.

2. FORMULATION OF THE PROBLEM

2.1 Cost function

One of the ways to supply energy is to use energy from the fuel. Generators using this method of energy are called thermal units. In thermal units, the cost function can be linear or nonlinear, or even a combination of these two. In the case of the economic dispatch, if the thermal unit is only available, the goal is to minimize production costs. However, this amount of production also has to satisfy a number of constraints. The ED issue is expressed as follows:

$$\text{Minimize} \quad F = \sum_{i=1}^{n} f_i(P_i) \tag{1}$$

In Eq. (1), P_i represents the generation of the generator i, n the total number of generators, and f is calculated as a quadratic equation in terms of the power generated by each generator. This quadratic equation can be expressed as Eq. (2)

$$f_i = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

In the Eq. (2), a_i, b_i and c_i, the constant coefficients depend on the generator i.

Of course, in some cases, in these types of power plants, turbines usually have several vents that are used to control the output power of each unit. The turbine heat velocity graph, in the process of opening the vent, is rippled, and sometimes even causes the cost function to be detached and not unified. In order to accurately model the effects of the vent valve, a sinusoidal function is added to the cost function [2, 5]. Equation (3) shows the cost function when the effect of the valve-point is also considered.

$$\text{Minimize} \quad F_C = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i + \left| d_i \sin\left\{e_i\left(P_i^{\min} - P_i\right)\right\}\right| \tag{3}$$

The coefficients d_i and e_i are coefficients representing the effect of point-valves. The term $p_{i,min}$ is the lowest generator i generation.

As mentioned, in thermal power plants one of the goals is to minimize the relationship of Eq. 1 with consideration of a series of adjectives, which are described below by the constraints of equality and non-equality.

2.1.1 System power limitations

The total power generating capacity of generators at any given time interval should be the supply of consumer demand as well as line losses if any.

$$\sum_{i=1}^{n} P_i = P_D + P_{loss} \tag{4}$$

2.1.2 Production limitations

Each generator should observe a minimum and maximum production.

$$P_{i,\min} \le P_i \le P_{i,\max} \tag{5}$$

2.1.3 Network losses

Network losses are a function of generation of generators. The matrix of coefficients B is used to express the network losses. The losses can be expressed as follows.

2.2 Emission function

As mentioned, the burning of fossils will destroy the environment. The emission function is modeled in two ways. In the first method, NO_X and SO_X pollutants are considered as distinct quadratic functions. (Eq. (6)).

$$\text{Minimize} \quad E = \sum_{i=1}^{n} \alpha_i P_i^2 + \beta_i P_i + \gamma_i \tag{6}$$

In the second method, the pollution function of fossil fuel plants is considered as a combination of No_x and So_x pollution targets, which is modeled as a sum of a second order function and exponential function [29]. The equation used for the emission function is shown in Eq. (7).

$$\text{Minimize} \quad F_E = \sum_{i=1}^{n} \alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i \exp(\delta_i P_i) \tag{7}$$

In the two equations above, coefficients α_i, β_i, γ_i, η_i, and δ_i are the coefficients of pollution curvature of generators.

3. PSO, MPSO AND AMPSO ALGORITHMS

3.1 PSO Algorithm

Particle Swarm Optimization Algorithm (PSO) in 1995 by Kennedy and Ebert for the first time as an uncertain search method for optimizing functions [30]. The PSO algorithm is inspired by a survey of animal behavior that is sought after by groups and without leaders such as fish and birds. Normally, in this case, given that there is no leadership, for example, each bird, also referred to as a particle, is individually and randomly looking for food. Each bird will tell the other birds the best they have seen. In the next step, each bird tries to adjust its path according to its best position and the best position seen by the whole group. These steps are repeated repeatedly to reach a suitable food supply.

In the PSO, the food is like the target, the particle is similar to the acceptable response, the best position seen by each particle, such as *Pbest*, and the best position seen by the whole group, such as *gbest*. At each stage, when the particles want to take a new position, their previous location changes by a speed. This speed includes components such as a coefficient of the previous particle velocity, a coefficient of difference between the current position and the *Pbest*, and a coefficient of difference between the current position of the particle of the *gbest*.

$$V_i(t)=V_i(t-1)+ c_1 r_1(Pbest(t)-x_i(t-1))+c_2 r_2(gbest(t)-x_i(t-1)) \quad (8)$$

$$x_i(t)=x_i(t-1)+V_i(t) \quad (9)$$

In the above relations, r_1 and r_2 are random numbers between 0 and 1, C_1 and c_2 are almost constant coefficients, usually between 1 and 3, and the coefficient *w* can be either constant or variable. If coefficient *w* is variables, this coefficient usually decreases with respect to the number of repetitions, so that it can be performed in the smaller interval of the search operation. Additionally, the self-generated coefficients obtained by equation (10) are also limited within a specified range, so that the velocity of each particle is not too large to allow it to search for more positions between two locations.

$$V_{\min} \le V_i \le V_{\max} \quad (10)$$

Typically, the speed range in the minimum and maximum sections is equally symmetric, and the coefficient of 0.2 to 0.3 is considered as the possible variation for each particle.

In the case of equation (9), it should also be noted that the new position also does not exceed the limits equation (5) if the boundary bound for each particle is exceeded by adding the velocity to the previous position. Different ways are considered when leaving the boundaries. In some cases, in the case of exit from the boundary, the previous position is considered, the other way of using repeated repetition of this section is given the randomness of the coefficients r1 and r2, until the output does not occur. As another solution, which is also used in this paper, consider the amount of new position in the same state as the new state wants to exceed it.

3.2 MPSO algorithm

The difference between the MPSO method and the PSO is to prevent the early convergence of the algorithm. n the standard PSO method, all members of the population are randomly generated. But in the modified method, instead of producing the whole population, at least one-third of the population is generated on a random basis, and two thirds of the rest of the population are produced according to equations (11) and (12). Which causes the particles to be distributed and dispersed in the search space [31].

$$X_{i+n/3,j}(t)=X_{i,j}(t)+r(X_{\max j}-X_{i,j}(t)) \quad (11)$$

$$X_{i+n/3,j}(t)=X_{i,j}(t)-r(X_{i,j}(t)-X_{\min j}) \quad (12)$$

where $j \in 1,2,...,d$ represents the dimension of the particle; $i \in 1,2,...,n/3$ and $k \in 1,2,...,n/3$ represent the two-third of n; X_{minj} ,X_{maxj} represent the minimum and maximum value related to the *j*th particle; *r* is a parameter in the interval [0, 1]. The population generated is evaluated and the target function is calculated for each member. Then, according to the fitness of each member, the population is sorted out and one third of the best results are selected. Two thirds of the population are produced according to the previous method. Then, according to equations (8) and (9), the speed and position of new members of the population are calculated and reassessed. By using this method, the population is diversified and the premature convergence is constantly avoided.

3.3 AMPSO algorithm

As noted, the MPSO method, by creating diversity in the population, and the use of equations (11) and (12) preventing early convergence.

In order to solve the ED problem, (given the fact that the problem is bounded) the MPSO method can have two minor objections. First, equation (12) can only be useful when the existing sample is included in the main third of the population and have a far higher production than its demands, so that even after applying this equation and the required deductions, it would be able to meet the demands. For example, if the total amount of production by the selected sample (Xk) is close to the expected amount (PD), then after applying the equation and deducing the required amount from the total production, some sample wouldn't be able to meet the equation and thus are removed from the possible answers. Second, (however it cannot be called a problem, it is better to be revised by the proposed method in this study) by using the abovementioned relations the results are obtained between the bounds and if the optimum answer is within the bounds, then given the random value of r, using these relations will lead to a sample far removed from the bounds. The sample can fall within the bounds only if the random value of r is 1, the possibility of which is very low. In MPSO method, the results could fall within the bounds, however it was facilitated by PSO algorithm guidance.

In order to correct the above mentioned issues, it is suggested in this article that the following relationships should be used instead of high-level equations.

$$X_{i+n/3,j}(t)=X_{i,j}(t)+r\times p\times(X_{\max j}-X_{i,j}(t)) \quad (13)$$

$$X_{i+n/3,j}(t)=X_{i,j}(t)-r\times p\times(X_{i,j}(t)-X_{\min j}) \quad (14)$$

In the above relations, p is a random vector with Gaussian level. The length of this vector is proportional to the number of variables and its value can be positive or negative. With regard to the positive or negative, the problem of generating the amount of production is also accidentally solved, so that some generators generate more and some of them, which makes the amount of production demanded, either in excess of production and Does not go far in terms of reducing production. On the other hand, the use of the *randn* function causes random numbers to be created. However, unlike the rand function, it is not limited to 0 to 1, and it is likely to produce a value greater than one, and this will cause the sample in one third of the original population to add a value that will cause the sample to be drawn from the boundaries get out. Of course, in this case, the specimens are limited to the boundary value.

4. SYSTEMS STUDIED AND SIMULATED

To study and simulate, four systems have been used in this paper. In all systems, the constrictions associated with the production limit and meeting the demands of the consumers are taken into consideration. Additionally, the losses as well as evaluation of various demands were also considered for the first studied system. The second studied system is also similar the first one, however their coefficients of production costs and the pollutants resulted from its fuels are different. In addition, loss parameters in the second studied system have non-negative coefficients. The third studied system not only has losses, but also uses non-convex functions in order to calculate the production cost and the pollutants. And the last studied system has zero losses and possesses more generators than other systems.

To use the proposed algorithm, since the modified particle-group algorithm method is used, a number of quantities should be used. The parameters needed and used for the proposed algorithm are: For all systems, the maximum number of repetitions of the program, 300, the C1 and C2 coefficients for determining the speed of displacement, 2, the coefficient w for using the speed of the previous mode, using the linear relationship with increasing program repetitions from 0.9 to 0.4 The size of the population for the first and second systems is 30 and for the second and third systems is 50 members.

4.1 The first study system

The first system studied, the IEEE 30-bos system, includes 6 generators. Figure 1 represents this system. The parameters of these thermal units as well as the coefficients related to the calculation of losses in this system are presented below [19, 21, 23, 32].

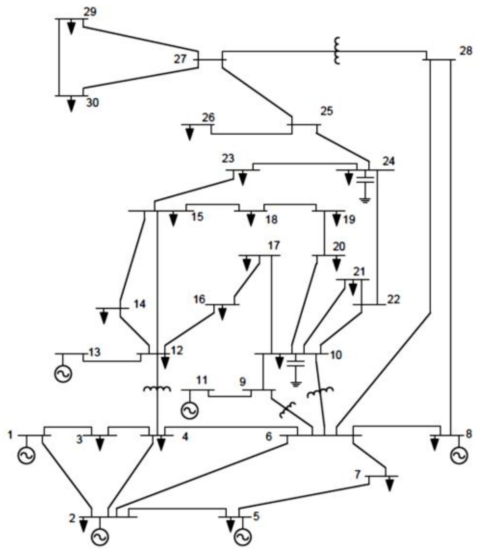

Figure 1. A single-line graph of a 30-buses system [21]

The data used for the system 6 generator is shown in Table 1. In these tables, the minimum and maximum production of each generator, along with the coefficients related to the cost of thermal power plants, and the coefficients of environmental emission are given. In equation (15), the coefficients required to calculate the losses from the production are given.

Table 1. The data of the first study system with 6 generators

Unit	$P_i^{\min}$ MW	$P_i^{\max}$ MW	a_i $(\$/MW^2)$	b_i $(\$/MW)$	c_i $(\$)$	α_i (kg/MW^2)	β_i (kg/MW)	γ_i (kg)
1	10	125	0.15240	38.53973	756.79886	0.00419	0.32767	13.85932
2	10	150	0.10587	46.15916	451.32513	0.00419	0.32767	13.85932
3	35	225	0.02803	40.39655	1049.9977	0.00683	-0.54551	40.26690
4	35	210	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.26690
5	130	325	0.02111	36.32782	1658.5596	0.00461	-0.51116	42.89553
6	125	315	0.01799	38.27041	1356.6592	0.00461	-0.51116	42.89553

$$B_{ij} = \begin{bmatrix} 0.002022 & -0.000286 & -0.000534 & -0.000565 & -0.000454 & -0.000103 \\ -0.000286 & 0.003243 & 0.000016 & -0.000307 & -0.000422 & -0.000147 \\ -0.000534 & 0.000016 & 0.002085 & 0.000831 & 0.000023 & -0.000270 \\ -0.000565 & -0.000307 & 0.000831 & 0.001129 & 0.000113 & -0.000295 \\ -0.000454 & -0.000422 & 0.000023 & 0.000113 & 0.000460 & -0.000153 \\ -0.000103 & -0.000147 & -0.000270 & -0.000295 & -0.000153 & 0.000898 \end{bmatrix} \quad (15)$$

This system is intended for power generation of 500, 700 and 900 megawatts of consumers. Also, the results obtained by using the FCGA and NSGA-II methods in [33] and the simulated annealing algorithm proposed in [32] have been evaluated. The results obtained for the best production cost and also the best mode for the lowest amount of emission are given in Table 2 to Table 7. Figure 2 to Figure 7 show the best results for cost and pollutants for this system, using MPSO and AMPSO methods.

Table 2. Best burning cost for 6 Generator System (PD = 500 MW)

Unit Output	FCGA [**33**]	NSGA-II [**33**]	SA [**32**]	MPSO	AMPSO
P1 (MW)	49.47	50.836	52.1024	56.8156935890555	53.2528556484217
P2 (MW)	29.40	31.806	29.0471	31.3264086603524	29.2366998975252
P3 (MW)	35.31	35.12	40.0000	35	35
P4 (MW)	70.42	73.44	68.0901	67.0717777582746	70.8291488635909
P5 (MW)	199.03	191.988	191.4150	200.002487649267	191.651842073973
P6 (MW)	135.22	135.019	136.4637	125	136.548198465143
Fuel cost ($/h)	28150.80	28150.834	28086.9456	28100.3069343317	**28079.5640350539**
Emission (kg/h)	314.53	309.04	306.3324	314.281007839111	308.956985526582
Power losses (MW)	18.86	18.208	17.1183	15.1474208816750	16.5154652531964
Total Capacity (MW)	518.86	518.208	517.1183	515.216367656949	516.518744948654

Table 3. Best burning cost for 6 Generator System (PD = 700 MW)

Unit Output	FCGA [33]	NSGA-II [33]	SA [32]	MPSO	AMPSO
P1 (MW)	72.14	76.179	76.0897	76.6185788947589	76.2496318918460
P2 (MW)	50.02	51.81	49.0586	48.5906054296108	49.0574601406460
P3 (MW)	46.47	49.82	45.3525	35	46.3029425702720
P4 (MW)	99.33	103.407	102.7347	97.3946023273525	102.565458804736
P5 (MW)	264.60	267.984	266.3914	283.577857523276	265.074629661369
P6 (MW)	203.58	184.734	191.3422	189.052960798199	191.783140647205
Fuel cost ($/h)	38384.09	38370.746	38207.5910	38250.0484628935	**38207.4080100437**
Emission (kg/h)	543.48	534.924	532.6970	564.387895997333	534.782354869843
Power losses (MW)	36.15	33.934	30.9692	30.0796551260958	31.0330662605615
Total Capacity (MW)	736.14	733.934	730.9692	730.234604973197	731.033263716074

Table 4. Best burning cost for 6 Generator System (PD = 900 MW)

Unit Output	FCGA [33]	NSGA-II [33]	SA [32]	MPSO	AMPSO
P1 (MW)	101.11	102.963	103.4811	96.1303515831655	104.409181662226
P2 (MW)	67.64	74.235	70.1005	76.6507269074873	69.8274108084915
P3 (MW)	50.39	66.003	60.6818	57.8551324035686	60.4506010676294
P4 (MW)	158.80	140.316	139.5618	138.378541958455	139.879798577953
P5 (MW)	324.08	324.888	325.0000	325	325
P6 (MW)	256.56	248.416	251.7912	258.586318022849	250.663469311898
Fuel cost ($/h)	49655.40	49620.824	49297.9331	49336.2679486580	**49297.5583643102**
Emission (kg/h)	877.61	849.326	845.6922	857.477040439712	848.887965428138
Power losses (MW)	58.58	56.822	50.6162	52.5001243698674	50.2300801174249
Total Capacity (MW)	958.57	956.822	950.662	952.601070875525	950.230461428198

Table 5. Best mode of production for low emissions for 6 generator system (PD = 500 MW)

Unit Output	FCGA [33]	NSGA-II [33]	SA [32]	MPSO	AMPSO
P1 (MW)	81.08	56.931	58.064	59.5124120660608	57.5920480003965
P2 (MW)	13.93	41.542	43.721	44.0645958652345	43.6780288603029
P3 (MW)	66.37	73.896	75.725	79.4357687462550	75.3503345659488
P4 (MW)	85.58	84.931	83.975	87.1196146281147	83.8991180837333
P5 (MW)	141.70	136.502	133.454	130	134.269795119870
P6 (MW)	135.93	131.328	128.777	125	128.867840216908
Fuel cost ($/h)	28756.71	28641.078	28626.520	28726.1447595866	28615.3929840889
Emission (kg/h)	286.59	275.544	274.254	274.631015802038	**274.264220933312**
Power losses (MW)	24.61	25.129	23.717 2	25.1016162491025	23.6523264772521
Total Capacity (MW)	524.61	525.129	523.7160	525.132391305665	523.657164847160

Table 6. Best mode of production for low emissions for 6 generator system (PD = 700 MW)

Unit Output	**FCGA [33]**	**NSGA-II [33]**	**SA [32]**	**MPSO**	**AMPSO**
P1 (MW)	120.16	103.078	105.329	103.889035305162	105.5352
P2 (MW)	21.36	73.505	76.408	67.4698428562764	76.7181
P3 (MW)	62.09	91.556	92.920	79.1085387956764	92.5700
P4 (MW)	128.05	110.787	109.834	109.048075157508	109.7361
P5 (MW)	209.65	187.869	183.192	199.113032652397	183.3517
P6 (MW)	201.12	174.289	170.013	173.931833876060	169.6465
Fuel cost ($/h)	39455.00	39473.433	39433.477	39002.7554927002	39436.7556
Emission (kg/h)	516.55	467.388	462.716	467.354900367730	**462.7201**
Power losses (MW)	42.44	41.083	37.6986	31.9860740998074	37.5576
Total Capacity (MW)	742.44	741.083	737.6960	732.560358643080	737.5576

Table 7. Best mode of production for low emissions for 6 generator system (PD = 900 MW)

Unit Output	FCGA [33]	NSGA-II [33]	SA [32]	MPSO	AMPSO
P1 (MW)	133.31	124.998	124.989	125	125
P2 (MW)	110.00	109.893	88.322	111.032550694093	111.732257087140
P3 (MW)	100.38	111.081	123.954	115.320869863807	111.787138695610
P4 (MW)	119.27	141.961	134.833	131.605681182323	141.985614857679
P5 (MW)	250.79	254.36	274.647	253.271370167208	248.587846723923
P6 (MW)	251.25	226.578	215.480	227.359983548224	224.576783781916
Fuel cost ($/h)	53299.64	51254.195	50517.633	51018.7105615702	51051.6717772173
Emission (kg/h)	785.64	760.052	751.274	751.272923395822	**749.517949417608**
Power losses (MW)	65.00	68.87	62.226	63.2086573379944	63.6675062730368
Total Capacity (MW)	965.00	968.87	962.226	963.590455455654	963.669641146267

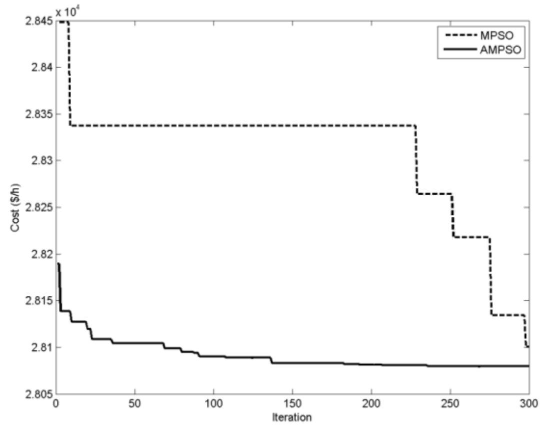

Figure 2. The lowest cost per iteration for a system of 6 generators with a demand of 500 megawatts

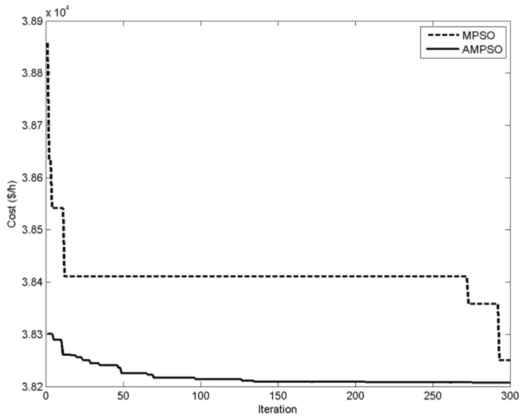

Figure 3. The lowest cost per iteration for a system of 6 generators with a demand of 700 megawatts

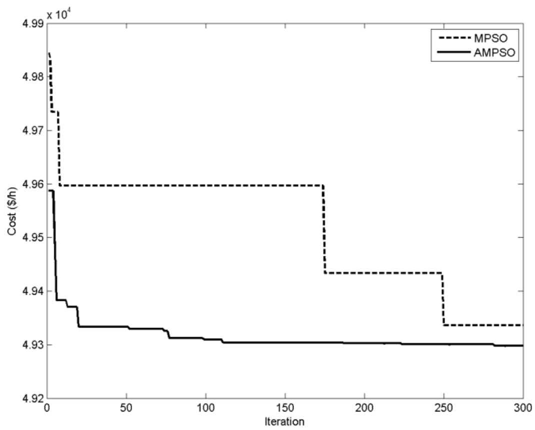

Figure 4. The lowest cost per iteration for a system of 6 generators with a demand of 900 megawatts

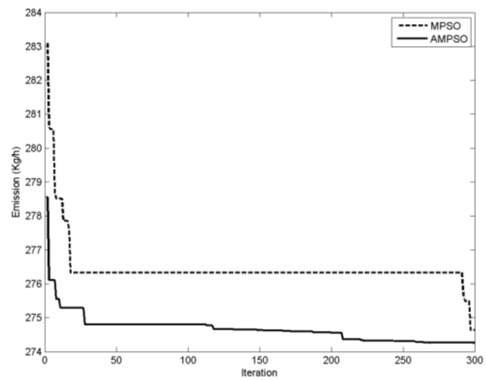

Figure 5. The lowest amount of emission in each iteration for a system of 6 generators with a demand of 500 megawatts

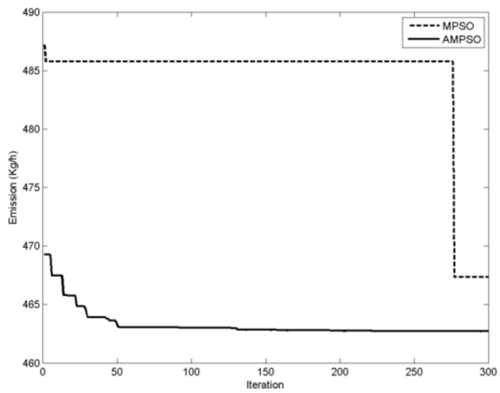

Figure 6. The lowest amount of emission in each iteration for a system of 6 generators with a demand of 700 megawatts

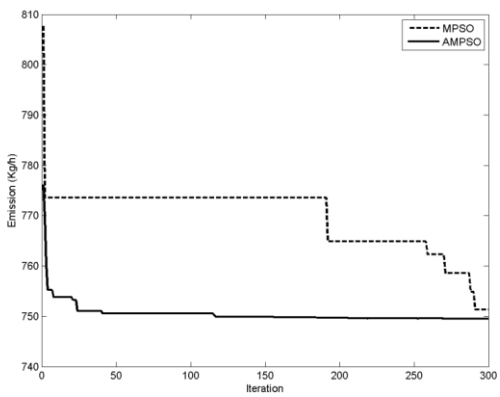

Figure 7. The lowest amount of emission in each iteration for a system of 6 generators with a demand of 900 megawatts

According to the results, as can be seen, in all cases of production, the cost of production is a better result. In the case of emission, the proposed algorithm seems to have worked well for only 900 megawatts, but with a small amount of precision, it is observed that in the SA method at 500 and 700 megawatts, the results are slightly inconsistent with the production, which made this the method provides a better result. For example, it can be mentioned about 700 that the SA method is 737.6960 megawatts and that it is 37.6986 megawatts, which will produce 699.9974 megawatts instead of 700 megawatts, resulting in a difference of 0.0041 in pollutants Has been. (Difference between 462.716 and 462.7201). In other words, we can say that if we examine it carefully, we can see that the proposed algorithm offers better results.

4.2 The second study system

For the second study system, the same 30-busi IEEE system that includes the 6-generator system is considered [**34**]. But the coefficients for calculating the cost of production and calculating the amount of pollution are slightly different from the first system. But the parameters for calculating losses are very high. The values for the lowest and most generators, as well as the parameters required to calculate the production cost and the amount of emission, were given using the second-order function in Table 8. Equation (16) also shows the parameters for calculating casualties.

Table 8. The data of the second study system with 6 generators

Unit	P_i^{min} MW	P_i^{max} MW	a_i $(\$/MW^2)$	b_i $(\$/MW)$	c_i $(\$)$	α_i (kg/MW^2)	β_i (kg/MW)	γ_i (kg)
1	10	125	0.15247	38.539	756.7988	0.00419	0.32767	13.8593
2	10	150	0.10587	46.1591	451.3251	0.00419	0.32767	13.8593
3	35	210	0.03546	38.3055	1243.531	0.00683	-0.54551	40.2669
4	35	225	0.02803	40.3965	1049.998	0.00683	-0.54551	40.2669
5	125	315	0.01799	38.2704	1356.659	0.00461	-0.51116	42.8955
6	130	325	0.02111	36.3278	1658.57	0.00461	-0.51116	42.8955

$$B_{ij} = \begin{bmatrix} 0.000140 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix} \quad (16)$$

The demand for this system is 1200 megawatts. In order to examine and analyze the results, in addition to the MPSO method, the NSGA-III method used in [**35**] was also evaluated. The results are presented in Table 9. The Figure 8 is also the best answer for the cost of production and Figure 9 The best amount of emissions is displayed at the lowest value for the MPSO and the proposed method.

Table 9. Results obtained for the second study system

	Emission dispatch	**Economic dispatch**	**MPSO Cost**	**AMPSO - Cost**	**MPSO - Emission**	**AMPSO - Emission**
P1 (MW)	125	84.6285	83.5080707378572	84.6866	125	125
P2 (MW)	150	93.4213	94.5150	93.3646	150	150
P3 (MW)	201.4824	210	210	210	202.0594	201.8410
P4 (MW)	198.8723	225	225	225	198.2827	199.1528
P5 (MW)	288.5129	315	315	315	289.1071	287.0505
P6 (MW)	286.2913	325	325	325	285.7202	287.1110
Cost ($)	65992	64099.2798	64099.6210	**64099.2800**	65993.0662	65993.7362
Emission (lb)	1240.66	1345.9	1345.9162	1345.8504	1240.7201	**1240.6747**
loss	50.1590	53.0498	53.0227	53.0512	50.1507	50.1501
Total generation	1250.1589	1253.0498	1253.0231	1253.0512	1250.1694	1250.1553

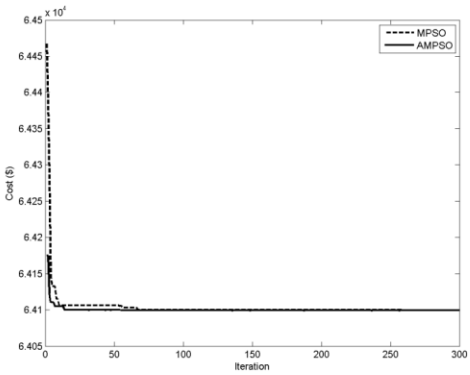

Figure 8. The lowest cost obtained in each iteration for the second study system

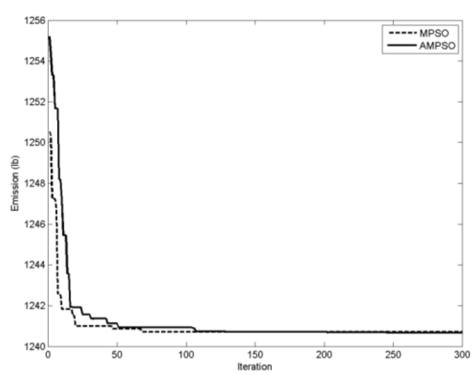

Figure 9. The lowest amount of emission obtained in each iteration for the second study system

The results obtained for this system are similar to the NSGA-III method. In other words, for this system, both solutions are best suited to minimize the goals of this system. In the case of reduced emissions, the difference is due to more production.

4.3 Third study system

This system is known as New England and includes 39 bus, 46 branches and 10 generators [**34**]. Figure 10 shows the single-line graph of this system. Table 10 shows the parameters for the lowest and the highest production rate of each generator, as well as the parameters for calculating cost and emission. In this system, in order to calculate the cost of production, the effects of steam valves are also considered. To calculate the amount of emission, the equation (7) is also used. In Equation (17), the coefficients required to calculate network losses are given

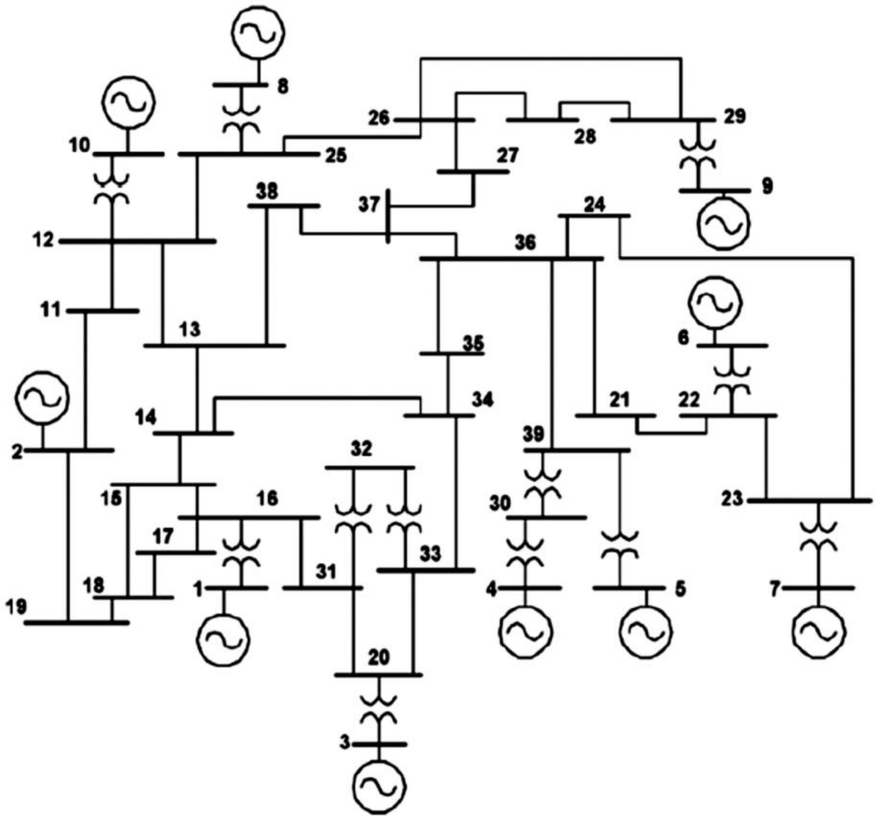

Figure 10. The single-line graph of the system studied by 10 generators [34]

Table 10. System data for 10 generators

Unit	P_i^{min} MW	P_i^{max} MW	a_i $(\$/MW^2)$	b_i $(\$/MW)$	c_i $(\$)$	d_i	e_i	α_i (kg/MW^2)	β_i (kg/MW)	γ_i (kg)	η_i	δ_i
1	10	55	0.12951	40.5407	1000.403	33	0.0174	0.04702	-3.9864	360.0012	0.25475	0.01234
2	20	80	0.10908	39.5804	950.606	25	0.0178	0.04652	-3.9524	350.0012	0.25475	0.01234
3	47	120	0.12511	36.5104	900.705	32	0.0162	0.04652	-3.9023	330.0056	0.25163	0.01215
4	20	130	0.12111	39.5104	800.705	30	0.0168	0.04652	-3.9023	330.0056	0.25163	0.01215
5	50	160	0.15247	38.539	756.799	30	0.0148	0.0042	0.3277	13.8593	0.2497	0.012
6	70	240	0.10587	46.1592	451.325	20	0.0163	0.0042	0.3277	13.8593	0.2497	0.012
7	60	300	0.03546	38.3055	1243.531	20	0.0152	0.0068	-0.5455	40.2699	0.248	0.0129
8	70	340	0.02803	40.3965	1049.998	30	0.0128	0.0068	-0.5455	40.2699	0.2499	0.01203
9	135	470	0.02111	36.3278	1658.569	60	0.0136	0.0046	-0.5112	42.8955	0.2547	0.01234
10	150	470	0.01799	38.2704	1356.659	40	0.0141	0.0046	-0.5112	42.8955	0.2547	0.01234

$$B_{ij} = \begin{bmatrix} 0.000049 & 0.000014 & 0.000015 & 0.000015 & 0.000016 & 0.000017 & 0.000017 & 0.000018 & 0.000019 & 0.000020 \\ 0.000014 & 0.000045 & 0.000016 & 0.000016 & 0.000017 & 0.000015 & 0.000015 & 0.000016 & 0.000018 & 0.000018 \\ 0.000015 & 0.000016 & 0.000039 & 0.000010 & 0.000012 & 0.000012 & 0.000014 & 0.000014 & 0.000016 & 0.000016 \\ 0.000015 & 0.000016 & 0.000010 & 0.000040 & 0.000014 & 0.000010 & 0.000011 & 0.000012 & 0.000014 & 0.000015 \\ 0.000016 & 0.000017 & 0.000012 & 0.000014 & 0.000035 & 0.000011 & 0.000013 & 0.000013 & 0.000015 & 0.000016 \\ 0.000017 & 0.000015 & 0.000012 & 0.000010 & 0.000011 & 0.000036 & 0.000012 & 0.000012 & 0.000014 & 0.000015 \\ 0.000017 & 0.000015 & 0.000014 & 0.000011 & 0.000013 & 0.000012 & 0.000038 & 0.000016 & 0.000016 & 0.000018 \\ 0.000018 & 0.000016 & 0.000014 & 0.000012 & 0.000013 & 0.000012 & 0.000016 & 0.000040 & 0.000015 & 0.000016 \\ 0.000019 & 0.000018 & 0.000016 & 0.000014 & 0.000015 & 0.000014 & 0.000016 & 0.000015 & 0.000042 & 0.000019 \\ 0.000020 & 0.000018 & 0.000016 & 0.000015 & 0.000016 & 0.000015 & 0.000018 & 0.000016 & 0.000019 & 0.000044 \end{bmatrix} \quad (17)$$

The demand for the system for consumers is 2000 MW. The results of implementing the proposed algorithm for this system are presented in Table 11. For comparing and analyzing the results, the MPSO method and the results obtained in [35] were used by the NSGA-III method. The Figure 11 is also the best answer for the cost of production and Figure 12 The best amount of emissions is displayed at the lowest value for the MPSO and the proposed method.

Table 11. The results obtained for the 10-generation system

	Emission dispatch	**Economic dispatch**	**MPSO Cost**	**AMPSO - Cost**	**MPSO - Emission**	**AMPSO - Emission**
P1 (MW)	55	55	55	55	55	55
P2 (MW)	79.9782	80	80	80	80	80
P3 (MW)	82.1289	106.0514	120	105.9658	81.0634	80.9035
P4 (MW)	82.3506	99.2176	98.4211	101.0017	82.2904	80.8410
P5 (MW)	160	81.5808	76.7119	82.0455	160	160
P6 (MW)	240	85.1964	77.0012	83.0223	240	240
P7 (MW)	296.1872	299.9843	300	300	300	294.5655
P8 (MW)	296.2329	340	340	340	293.5602	296.7405
P9 (MW)	397.4092	470	470	470	395.5318	398.2191
P10 (MW)	392.2266	470	470	470	394.1809	395.3546
Cost	1.16430	111498.4972	111527.2706	**111497.8929**	116442.3183	116409.4612
Emission (lb)	3932.50	4562	4636.8518	4569.2309	3932.9532	**3932.2816**
loss	81.5137	87.0305	87.1244	87.0342	81.5495	81.6233
coltolid	2081.5136	2087.0305	2087.1342	2087.0353	2081.6266	2081.6242

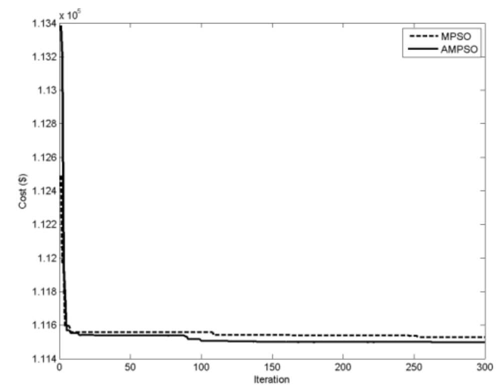

Figure 11. The lowest cost obtained in each iteration for a 10-generation system

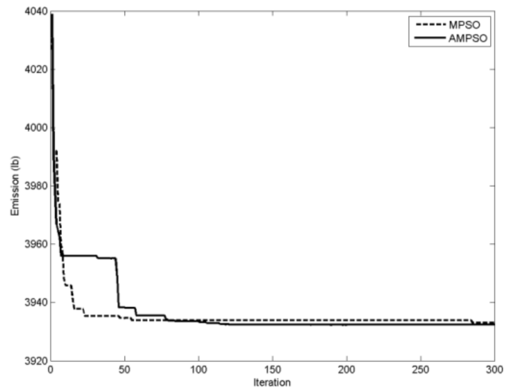

Figure 12. The lowest emission obtained in each iteration for a 10-generation system

According to the results, it can be seen that, despite a slightly higher demand than demand, better results than the other methods have been obtained for both the best production cost and the best mode of production of emissions.

4.4 The fourth study system

In this system, known as the IEEE 118 bus system, there are 118 bus, 186 branches, 9 transformers, 14 compensating shunt and 14 generators [34]. The Table 12 shows the parameters for the least and the highest production rate of each generator, as well as the parameters for calculating cost and emission. There are no loss in this system.

The demand for the system for consumers is 950 megawatts. The results of implementing the proposed algorithm for this system are presented in Table 13. For comparing and analyzing the results, the MPSO method and the results obtained in [**35**] were used by the NSGA-III method. Figure 13 shows the best results for cost and Figure 14 shows the best results for the emission associated with this system 14 generators in the iterations of the program.

By assessing the results, it is seen that, for the best production cost, the results obtained are approximately the same as those obtained by the NSGA-III method, with a slight difference, but for the mode of emission, the AMPSO method has achieved a much better result. The best result obtained by the NSGA-III method was 24.0935. Using the proposed algorithm for this state, the value of 17.61530 was obtained, showing a difference of 6.4785, indicating the ability to find better response to the proposed method than the NSGA-III method.

Table 12. System data for 14 generators

Unit	P_i^{min} MW	P_i^{max} MW	a_i $(\$/MW^2)$	b_i $(\$/MW)$	c_i $(\$)$	α_i (kg/MW^2)	β_i (kg/MW)	γ_i (kg)
1	50	300	0.005	1.89	150	0.016	-1.5	23.333
2	50	300	0.0055	2	115	0.031	-1.82	21.022
3	50	300	0.006	3.5	40	0.013	-1.249	22.05
4	50	300	0.005	3.15	122	0.012	-1.355	22.983
5	50	300	0.005	3.05	125	0.02	-1.9	21.313

6	50	300	0.007	2.75	70	0.007	0.805	21.9
7	50	300	0.007	3.45	70	0.015	-1.401	23.001
8	50	300	0.007	3.45	70	0.018	-1.8	24.003
9	50	300	0.005	2.45	130	0.019	-2	25.121
10	50	300	0.005	2.45	130	0.012	-1.36	22.99
11	50	300	0.0055	2.35	135	0.033	-2.1	27.01
12	50	300	0.0045	1.3	200	0.018	-1.8	25.101
13	50	300	0.007	3.45	70	0.018	-1.81	24.313
14	50	300	0.006	3.89	45	0.03	-1.921	27.119

Table 13. The results obtained for the 14-generation system

	Emission dispatch	**Economic dispatch**	**MPSO - Cost**	**AMPSO - Cost**	**MPSO - Emission**	**AMPSO - Emission**
P1 (MW)	69.8127	109.8844	113.795823726347	111.4598	79.0886143379699	70.1796916413912
P2 (MW)	51.8311	89.4884	90.4939562589807	90.4074	50	50
P3 (MW)	62.2194	50	50	50	85.7428479488527	76.1645287026293
P4 (MW)	83.7883	50	50	50	92.5736728840073	89.7504382439757
P5 (MW)	71.0165	50	50	50	50	66.4535597500119
P6 (MW)	50	50	50	50	50	50
P7 (MW)	71.4004	50	50	50	78.4517701948822	72.0603383479059
P8 (MW)	74.0650	50	50	50	78.5145617314843	70.5635293730562
P9 (MW)	74.7153	50	50	50.7363	50	71.8507411217795
P10 (MW)	88.5315	52.9982	50	50.7319	89.7306458515212	90.3098468203007
P11 (MW)	50	59.1441	50	57.7153	50	50
P12 (MW)	81.0543	188.4848	195.711950133214	188.9519	73.5083748502815	70.4540928380279
P13 (MW)	71.5655	50	50	50	73.3315530909401	72.2867084258600
P14 (MW)	50	50	50	50	50	50
Cost ($)	4485	4264.6	4265.38961409069	**4264.6330**	4539.29941905666	4514.93609559280
Emission (lb)	24.0935	446.5254	482.047439090766	453.2149	37.4314445556441	**17.6153024952325**
Total Generation	950	949.9999	950.001730118541	950.0026	950.942040889940	950.073475264938

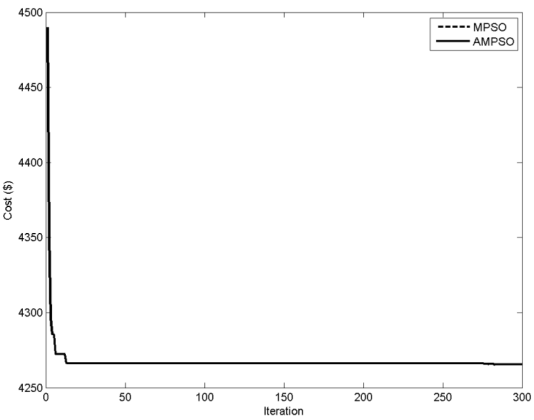

Figure 13. The lowest cost obtained in each iteration for a 14-generation system

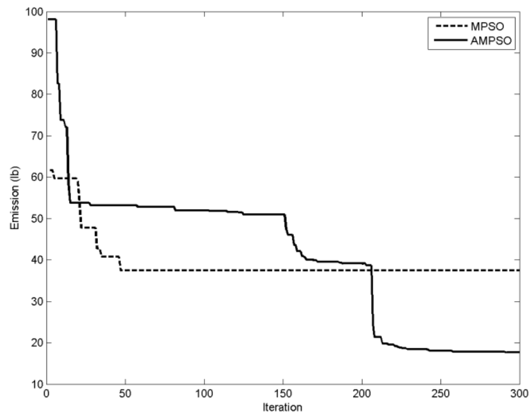

Figure 14. The lowest emission obtained in each iteration for a 14-generation system

5. CONCLUSION

In this paper, a new method is proposed for solving the economic dispatch problem. The main objectives considered for this problems were: reducing the production costs, and reducing the emission resulted from the production process; both of which were addressed in this study. Some systems have considered the pipeline losses, which has no effects of some systems. Some systems have considered the effect of steam valve opening. The results obtained by the proposed method are evaluated and compared to the results obtained by other methods. It can be concluded that the proposed method is superior for obtaining the best possible results. The obtained responses lead to the reduction of production costs and/or the reduction of environmental pollutants.

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