Optimizing Weight Factors in Multi-Objective Simulated Annealing for Dynamic Economic/Emission Dispatch

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Abstract: - This paper presents a Simulated Annealing Optimization to solve a Dynamic Economic/Emission Dispatch problem. In this work, the problem is formulated as a multi-objective one with two competing functions, namely economic cost and emission functions, subject to different constraints. The inequality constraints considered are the generating unit capacity limits while the equality constraint is generation-demand balance. To show the advantages of the proposed algorithm, it has been applied for solving multi-objective EELD problems in a 6-generators system considering NO_x, SO_2, and CO_2 emission. This technique is compared with other techniques which reveals the superiority of the proposed approach and confirms its potential for solving other power systems problems.

Key-Words: - Economic dispatch, multi-objective optimization, weight factors, simulated annealing.

1 Introduction

Economic Dispatch (ED) optimization is the most important issue which is to be taken into consideration in power systems. The problem of ED in power systems is to plan the power output for each devoted generator unit in such a way that the operating cost is minimized and simultaneously, matching load demand, power operating limits and maintaining stability. The gaseous pollutants emitted by the power stations cause harmful effects with the human beings and the environment like the sulphur dioxide (SO_2), nitrogen oxide (NO_x) and the carbon dioxide (CO_2), etc [1]. Thus, the optimization of production cost should not be the only objective but the reduction of emission must also be taken into account.

Thus, the ED problem can be handled as a multi-objective optimization problem that the objective functions are the total cost of electrical energy and the total emission function [2].

In general, multi-objective optimization problems are solved by reducing them to a scalar equivalent. This is achieved by aggregating the objective functions into a single function [3].

Recently, multi-objective algorithms have also been used to solve the Dynamic Generation Dispatch problem. IBPVT approach [4], particle swarm optimization (PSO) [5], genetic algorithm (GA) [6], linear programming [7], and new multi-objective stochastic search [8] are proposed to solve EED multi-objective problem by generating the Pareto optimal solution.

2 Dispatch Problem Formulation

The objective of solving the economic dispatch problem in electric power system is to determine the generation levels for all on-line units which minimize the total fuel cost and minimizing the emission level of the system, while satisfying a set of constraints.

2.1 Economic /Emission Dispatch

The present formulation treats the EELD problem as a multi-objective mathematical programming problem which is concerned with the attempt to minimize each objective simultaneously. The equality and inequality constraints of the system must meanwhile, be satisfied. The following objectives and constraints are taken into account in the formulation of the EELD problem.

The economic dispatch problem can be modeled by

$$\min F_T(P) = \sum_{i=1}^{n} F_i(P_i) \qquad (1)$$

where F_T is the total fuel cost; $F_T(P_i)$ is the fuel cost of generating unit i; n is the no. of generator.

Fuel Cost Function: The fuel cost function of a generating unit is usually described by a quadratic function of power output P_i as:

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

where a_i, b_i and c_i are the cost co-efficient of unit i.
Emission Equation: The Emission equation kg/hr of a generating unit is usually described by a quadratic function of power output P_i as:

$$E_{SO2i}(P_i) = d_{SO2i} P_i^2 + e_{SO2i} P_i + f_{SO2i} \quad (3)$$

where d_{SO2i} , e_{SO2i} and f_{SO2i} are the SO_2 emission co-efficient of unit i.

Similarly, the emission dispatch problem for NO_x can be defined as the following optimization problem

$$E_{NOxi}(P_i) = d_{NOxi} P_i^2 + e_{NOxi} P_i + f_{NOxi} \quad (4)$$

where d_{NOxi}, e_{NOxi} and f_{NOxi} are the NO_x emission co-efficient of unit i.

The emission dispatch problem for CO_2 can be defined as the following optimization problem

$$E_{CO2i}(P_i) = d_{CO2i} P_i^2 + e_{CO2i} P_i + f_{CO2i} \quad (5)$$

where d_{CO2i} , e_{CO2i} and f_{CO2i} are the CO_2 emission co-efficient of unit *i*.

Transmission losses: The transmission losses P_L can be found using B-coefficients

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij} P_i P_i \quad (6)$$

where Bij is the transmission line coefficients.

Power Balance Constraints: The total supply must be equal to power demand

$$\sum P_i = P_D + P_L \quad (7)$$

where PD is the load demand.

Generator limit Constraints: The power generation of unit *i* should be between its minimum and maximum limits.

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

where $P_{i\,min}$ is the minimum generation limit of unit *i* and $P_{i\,max}$ is the maximum generation limit of unit *i*.

3 Multi-Objective Dispatch Model

The multi-objective problem (MOP) is almost always solved by combining the multiple objectives $f_i\ (x)$ into one scalar objective whose solution is the so-called “Pareto optimal point” for the original MOP [9]. A solution vector *x* is said to be Pareto optimal if all other vectors have a higher value for at least one of the objective function f_i , or else have the same value for all objectives. The standard technique is to form a positively-weighted sum of objectives, that is,

$$F(x) = \sum_{i=1}^{n} w_i f_i(x); w_i > 0, i = 1 \ldots n \quad (9)$$

The general structure of multi-objective generation and emission dispatch problem is expressed as- find:

$$P = [P_1, P_2, \cdots, P_N]^T ; \min F = [F_{FC}, F_{SX}, F_{NX}, F_{CX}] \quad (10)$$

Subject to:

$$h(P_i) = 0;\ g(P_i) \le 0 \quad (11)$$

The above mentioned multi- objective optimization problem can be converted to a single objective optimization problem by introducing price penalty factors as follows:

$$\begin{aligned} F_{Ti}(P_i) &= w_1 F(P_i) + w_2 E_{SO2i}(P_i) + \\ & w_3 E_{NOxi}(P_i) + w_4 E_{CO2i}(P_i) \end{aligned} \quad (12)$$

where h_{SO2}, h_{NOx} and h_{CO2} are price penalty factors for SO_2, NO_x, and CO_2, respectively, blending the emission costs with the normal fuel costs.

4 A Simulated Annealing Algorithm For Multi-Objective Dispatch Model

The concept of simulated annealing was first introduced in the field of optimization in the early 1980’s by Kirkpatrick and independently by Cerny [10]. Simulated annealing is a robust, general-purpose combinatorial optimization algorithm based on probabilistic methods which has been applied successfully to many areas such as VLSI circuit design, neural-networks, image processing, code design, capacitor placement in power systems, and economic load dispatch.

4.1 Analogy to Physical Annealing

The name simulated annealing comes from an analogy between combinatorial optimization and the physical process of annealing. In physical annealing a solid is cooled very slowly, starting from a high temperature, in order to achieve a state of minimum internal energy. It is cooled slowly so that thermal equilibrium is achieved at each temperature. Thermal equilibrium can be characterized by the Boltzmann distribution

$$P_T\left\{X = x\right\} = (e^{-E_X/k_BT})/(\sum_i e^{-E_i/k_BT})$$

(13)

where X is a random variable indicating the current state, E_X is the energy of state x, k_B is Boltzmann's constant, and T is temperature.

The evolution of the state of a solid in a heat bath toward thermal equilibrium can be efficiently simulated by a simple algorithm based on Monte Carlo techniques which was proposed by Metropolis [11] in 1953. The *Metropolis algorithm* takes the current state x, and generates a new state y by applying some small perturbation. The transition from state x to state y is then accepted with probability

$$P_{accept}\left\{x, y\right\} = \begin{cases} 1, & if\ E_X - E_Y \le 0 \\ e^{-(E_x - E_y)/k_BT}, & if\ E - E > 0 \end{cases} \quad (14)$$

If accepted, y becomes the current state and the procedure is repeated. This acceptance rule is known as the *Metropolis criterion*. Given a particular combinatorial optimization problem let the solution x correspond to the current state of the solid, the cost function correspond to the energy of the current state, and the control parameter T correspond to the temperature of the solid. The simulated annealing algorithm consists simply of iterating the Metropolis algorithm for decreasing values of the artificial temperature parameter T.

Table 1. Simulated vs. Physical Annealing.

Optimization Problem	Physical System
solution x	current state of the solid
cost or objective value f(x)	energy of current state
control parameter T	temperature
optimal solution xopt	ground state
simulated annealing	gradual cooling

Some of the analogies between the thermal process of physical annealing and the artificial process of simulated annealing in a combinatorial optimization problem are summarized in Table 1.

4.2 Control Parameters of SA Algorithm

The algorithm of simulated annealing consists of operating parameters [12], [13], which should be well set in order to achieve its best performance. These are briefly mentioned in the following.

Initial Temperature

At beginning, initial temperature must be set at a higher value, in order to get more probability of acceptance for non optimized solutions during the first stages of the algorithm. Too much higher selection of initial temperature makes an algorithm slow and computationally inefficient.

Final Temperature

While working with SA algorithm generally the final temperature fall is set to zero degree Celsius. SA algorithm can take much longer time to execute the operation, if the decrement in the temperature is exponential in nature. Finally, the stopping criterion is selected, which can be either an appropriate low temperature or the value where the system get freeze at that temperature

Temperature Decrement

As initial and final temperatures have predefined values, it is essential to find the approach of transition from starting to its final temperature as the success of algorithm depends on it. The decrement of temperature at time "t" is

$$T(t) = d/\log(t) \quad (15)$$

where d is a positive constant.

The temperature decrement can also be implemented using

$$T(t+1) = \alpha T$$

(16)

where a, is a constant close to 1.

Iterations at each Temperature

To enhance efficiency of the algorithm, selection of proper number of iterations is another important factor. The realization of only iteration for each temperature and the fall in temperature should take place at a really slow rate which can be expressed as:

$$T(t) = t/(1 + \beta t) \quad (17)$$

Generally, β have very small value.

4.3 Simulated Annealing Algorithm

The SA algorithm for dispatch problem is stepped as follows:

Step 1: Initialization of the values temperature T, parameter α and iterations number criterion. Find randomly, an initial feasible solution, which is assigned as the current solution S_i and perform ELD in order to calculate the total cost, F_{cost}, with the preconditions (7) and (8) fulfilled.

Step 2: Set the iteration counter to $\mu = 1$.

Step 3: Find a neighboring solution Sj through a random perturbation of the counter one and calculate the new total cost F_{cost}

Step 4: If the new solution is better, we accept it, if it is worse, we calculate the deviation of cost $\Delta S=S_j-S_i$ and generate a random number uniformly distributed over $\Omega \in (0,1)$.

If $e^{-\Delta S/t} \geq \Omega \in (0,1)$

Accept the new solution S_j to replace S_i

Step 5: If the stopping criterion is not satisfied, reduce temperature using parameter α: $T(t) = \alpha T$ and go to Step 2.

5 Results and Discussion

SA algorithm has been tested on a 6-generators system considering NO_x, SO_2, and CO_2 emission. The software was implemented by the MATLAB language. For conducting the test, the initial temperature is fixed at 0.4 C°, alpha is fixed at 0.5 and max tries is 10000. The final temperature is 1e-10 C°.

In this case study, the six-generator system is analyzed considering the four conflicting objectives: fuel cost, NO_x, SO_2, and CO_2 emission. The generator cost coefficients, emission coefficients, loss coefficients and the generation limits of 6 units system are taken from [14], and the load demand is 1800 MW. The cases considered are as follows:

Case I: Optimization of each of the four objectives individually.
Case II: Optimization of fuel cost and NO_x emission.
Case III: Optimization of fuel cost, NO_x emission and SO_2 emission.
Case IV: Optimization of fuel cost, NO_x emission, SO_2 emission and CO_2 emission.

5.1 Test case I

The Table 2 shows the distribution of load among generators as system demand for minimum cost, minimum NO_x emission, minimum SO_2 emission, and minimum CO_2 emission and the obtained results by SA are compared with multi-objective Bacterial Foraging Optimization (MBFA). The Table 2 presents the best compromise solution by SA which the load demand is 1800 MW. It also shows the resulting objective functions for the other three objectives according to the power generation level obtained by optimizing the forth objective.

Table 2. Comparison of best single objective

	Best fuel cost		**Best NO_x emission**		**Best SO_2 emission**		**Best CO_2 emission**	
	MBFA[14]	**SA**	**MBFA[14]**	**SA**	**MBFA[14]**	**SA**	**MBFA[14]**	**SA**
P_1	252.314	251.5019	198.536	195.4037	251.830	250.9682	246.1145927	249.4375
P_2	303.320	303.6470	211.814	215.4803	303.974	302.7547	338.3301668	334.0283
P_3	503.094	503.1659	538.274	536.1979	505.530	507.4539	379.5915598	393.4448
P_4	372.741	372.0385	327.091	329.1248	370.075	369.7931	398.9112072	383.3058
P_5	301.329	302.5767	476.825	479.4924	302.981	302.6213	338.3065614	345.6164
P_6	197.318	197.2907	195.130	192.5148	195.784	196.4407	241.222651	235.5642
Losses(MW)	130.116	130.2207	147.670	148.2140	130.174	130.0322	142.4767373	141.3971
Fuel cost ($/h)	**18721.390**	**18719.5671**	18950.609	18946.2843	18721.456	18719.6584	18807.918	18788.4499
NO_X Emission (kg/h)	2298.434	2281.0807	**2077.820**	**2070.1270**	2294.712	2277.1692	2424.912	2361.6487
SO_2 Emission (kg/h)	11222.989	11222.9923	11356.338	11356.5113	**11222.956**	**11222.9376**	11277.212	11266.5205
CO_2 Emission (kg/h)	60522.875	60467.7010	66911.032	66939.3092	60576.573	60620.7713	**58144.545**	**58066.3467**

5.2 Test case II

In this case, only the NO_x emission is considered in addition to the fuel cost objective. The non-inferior solution set is obtained using the SA and presented in Table 3. As shown in the table, the maximum and minimum values of W1 and W2 represent the two ends of the Pareto optimal front as illustrated in Figure 1. The power generation level of each unit corresponding to each of the non-dominated solutions is shown in Table 4.

Table 3. Non-dominant solutions for cost and NO_x objectives.

Solution Number	Weight		Objective	
	W1	W2	F1	F2
1	1	0	18719,5671	2281,0711
2	0,9	0,1	18721,6175	2242,0846
3	0,8	0,2	18727,7487	2207,3536
4	0,7	0,3	18738,0281	2176,5286
5	0,6	0,4	18752,5956	2149,4909
6	0,5	0,5	18771,6541	2126,2134
7	0,4	0,6	18795,4830	2106,7324
8	0,3	0,7	18824,4219	2091,1656
9	0,2	0,8	18858,8683	2079,6998
10	0,1	0,9	18899,2901	2072,5828
11	0	1	18946,2897	2070,1270

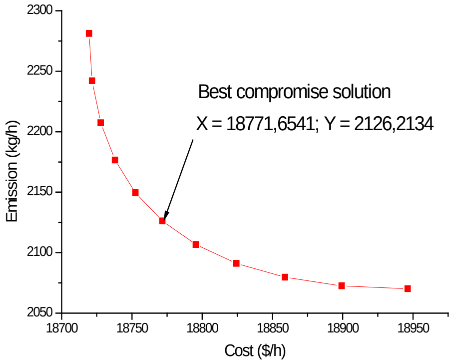

Fig.1. Pareto optimal front for cost and NO_x objectives.

Table .4. Power generation dispatch and losses.

Solution Number	Power Generation Dispatch						P_{loss} (MW)
	P1	P2	P3	P4	P5	P6	
1	251,5092	303,6419	503,1688	372,0336	302,5758	197,2907	130,2201
2	244,8774	295,8072	508,5718	365,3771	318,3301	197,7930	130,7566
3	238,5015	287,6986	513,3492	359,6084	334,3391	198,0398	131,5366
4	232,3727	279,3526	517,5887	354,5343	350,6794	198,0397	132,5674
5	226,4941	270,7696	521,3623	349,9696	367,4177	197,8461	133,8594
6	220,8564	261,9987	524,7109	345,8460	384,5897	197,4245	135,4261
7	215,4122	253,0407	527,6646	342,0416	402,2964	196,8361	137,2916
8	210,1723	243,8991	530,2805	338,5145	420,5640	196,0419	139,4724
9	205,0995	234,5862	532,5686	335,2110	439,4666	195,0654	141,9974
10	200,1865	225,1131	534,5349	332,0865	459,0839	193,8940	144,8990
11	195,3969	215,4882	536,1873	329,1322	479,4827	192,5258	148,2130

5.3 Test case III

In this case, a third objective, which is the SO_2 emission, is considered in this case in addition to the fuel cost and the NO_x emission. Three weighting factors are applied to convert this multi-objective optimization problem to a single one using the weighted-sum method.

These weights as well as the set of the non-dominated solutions are shown in Table 5 while the power generation level associated to this set is presented in Table 6. As shown in the table, the maximum and minimum values of W1, W2 and W3 represent the three ends of the Pareto optimal front as illustrated in Figure 2.

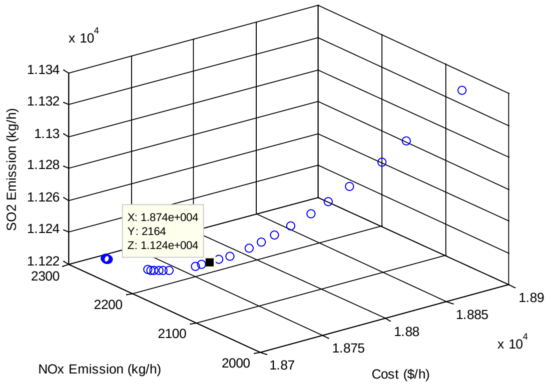

Fig.2 Three dimensional Pareto fronts for cost, NO_x and SO_2 objectives.

Table .5. Non-dominant solutions for cost, NOx and SO2 objectives.

Solution Number	Weight			Objective		
	W1	W2	W3	F1	F2	F3
1	1	0	0	18719,5671	2281,0799	11222,9921
2	0,85	0,15	0	18724,1689	2224,2292	11225,3982
3	0,7	0,3	0	18738,0290	2176,5265	11233,3630
4	0,55	0,45	0	18761,5466	2137,3830	11247,1180
5	0,4	0,6	0	18795,4809	2106,7338	11267,1119
6	0,25	0,75	0	18840,9388	2084,9028	11294,0023
7	0,1	0,9	0	18899,2906	2072,5827	11328,6047
8	0,85	0	0,15	18719,5679	2280,6946	11222,9824
9	0,7	0,15	0,15	18724,8354	2220,6064	11225,7652
10	0,55	0,3	0,15	18740,6079	2170,7905	11234,8546
11	0,4	0,45	0,15	18767,3893	2130,6573	11250,5438
12	0,25	0,6	0,15	18806,1991	2100,1550	11273,4357
13	0,1	0,75	0,15	18858,4232	2079,8123	11304,3545

14	0,7	0	0,3	18719,5709	2280,2678	11222,9722
15	0,55	0,15	0,3	18725,6501	2216,5409	11226,2165
16	0,4	0,3	0,3	18743,7200	2164,5201	11236,6590
17	0,25	0,45	0,3	18774,5438	2123,4059	11254,7447
18	0,1	0,6	0,3	18819,3743	2093,4178	11281,2175
19	0,55	0	0,45	18719,5768	2279,7826	11222,9624
20	0,4	0,15	0,45	18726,6549	2211,9664	11226,7768
21	0,25	0,3	0,45	18747,6033	2157,5031	11238,9166
22	0,1	0,45	0,45	18783,4181	2115,6276	11259,9641
23	0,4	0	0,6	18719,5872	2279,2192	11222,9530
24	0,25	0,15	0,6	18727,9222	2206,7445	11227,4874
25	0,1	0,3	0,6	18752,4789	2149,7083	11241,7564
26	0,25	0	0,75	18719,6048	2278,5447	11222,9447
27	0,1	0,15	0,75	18729,5403	2200,7677	11228,3996
28	0,1	0	0,9	18719,6321	2277,7383	11222,9390

Table. 6. Power generation dispatch and losses.

Solution Number	Power Generation Dispatch						P_{loss} (MW)
	P1	P2	P3	P4	P5	P6	
1	251,4925	303,6397	503,1837	372,0343	302,5863	197,2838	130,2203
2	241,6554	291,7853	511,0301	362,3886	326,3031	197,9539	131,1164
3	232,3792	279,3458	517,5843	354,5274	350,6828	198,0479	132,5674
4	223,6474	266,4075	523,0981	347,8510	375,9497	197,6538	134,6075
5	215,4105	253,0302	527,6852	342,0360	402,2972	196,8318	137,2910
6	207,6053	239,2638	531,4712	336,8316	429,9457	195,5746	140,6922
7	200,1736	225,1213	534,5374	332,0876	459,0861	193,8939	144,8998
8	251,4448	303,5613	503,6041	371,8028	302,5847	197,2040	130,2016
9	240,9895	290,9288	511,8887	361,6427	327,8499	197,8782	131,1779
10	231,1610	277,6188	518,7551	353,4527	353,8690	197,9252	132,7817
11	221,9572	263,7763	524,4353	346,5397	380,9250	197,4276	135,0610
12	213,3136	249,4398	529,0965	340,5128	409,2739	196,4489	138,0854
13	205,1324	234,6705	532,8962	335,1473	439,1261	194,9708	141,9432
14	251,3962	303,4557	504,0442	371,5809	302,5817	197,1218	130,1806
15	240,2375	289,9294	512,8517	360,8280	329,6086	197,7946	131,2498
16	229,8019	275,6471	520,0409	352,2542	357,5212	197,7742	133,0394
17	220,0783	260,7466	525,9206	345,0690	386,6588	197,1352	135,6086
18	210,9418	245,3307	530,6858	338,8400	417,2959	195,9520	139,0462
19	251,3345	303,3482	504,5685	371,3033	302,5961	197,0073	130,1579
20	239,3598	288,7905	513,9570	359,9155	331,6240	197,6897	131,3366
21	228,2587	273,3687	521,4901	350,9315	361,7185	197,5824	133,3498
22	217,9268	257,2711	527,5760	343,4465	393,2796	196,7763	136,2763
23	251,2567	303,2227	505,1936	370,9722	302,5955	196,8894	130,1302
24	238,3457	287,4545	515,2255	358,8687	333,9732	197,5756	131,4431
25	226,4546	270,7280	523,1582	349,4106	366,6423	197,3420	133,7357
26	251,1657	303,0619	505,9193	370,6098	302,6024	196,7386	130,0977
27	237,1964	285,8830	516,6810	357,6625	336,7415	197,4114	131,5759
28	251,0506	302,8923	506,7785	370,1484	302,6159	196,5757	130,0613

5.4 Test case IV

In this final case, the four emission objectives are taken into consideration. These are the fuel cost, NO_x, SO_2 and CO_2 emission. A weighting factor is assigned for each objective function so that the problem is converted into a single-objective optimization one. The obtained non-dominated solutions and the load dispatch are shown in Table 7 and Table 8 respectively.

Table. 7. Non-dominant solutions for cost, NO_x, SO_2 and CO_2 objectives.

Solution Number	Weight				Objective			
	W1	W2	W3	W4	F1	F2	F3	F4
1	1	0	0	0	18719,5671	2281,087	11222,9922	60468,0063
2	0,7	0,3	0	0	18738,0256	2176,5343	11233,3612	61113,1306
3	0,4	0,6	0	0	18795,4751	2106,7377	11267,1084	62793,1620
4	0,1	0,9	0	0	18899,3117	2072,5804	11328,6174	65665,7840
5	0,7	0	0,3	0	18719,5709	2280,2310	11222,9721	60498,7204
6	0,4	0,3	0,3	0	18743,7399	2164,4819	11236,6705	61320,5160
7	0,1	0,6	0,3	0	18819,3707	2093,4194	11281,2154	63498,5140
8	0,4	0	0,6	0	18719,5873	2279,1925	11222,953	60538,9046
9	0,1	0,3	0,6	0	18752,4803	2149,7058	11241,7574	61625,3739
10	0,1	0	0,9	0	18719,6316	2277,7803	11222,9391	60596,1489
11	0,7	0	0	0,3	18779,6657	2351,9499	11261,1283	58076,2247
12	0,4	0,3	0	0,3	18779,5655	2337,4930	11260,9950	58083,6418
13	0,1	0,6	0	0,3	18779,9859	2323,5507	11261,174	58104,2154
14	0,4	0	0,3	0,3	18780,9934	2353,35185	11261,9437	58073,3853
15	0,1	0,3	0,3	0,3	18780,8981	2338,70741	11261,8125	58080,9107
16	0,1	0	0,6	0,3	18782,362	2354,79107	11262,7838	58070,9863
17	0,4	0	0	0,6	18785,7523	2358,6546	11264,8656	58067,2325
18	0,1	0,3	0	0,6	18785,6038	2350,89714	11264,7377	58069,2361
19	0,1	0	0,3	0,6	18786,5097	2359,46411	11265,3301	58066,8021
20	0,1	0	0	0,9	18787,9823	2361,13854	11266,2336	58066,3727

Table. 8. Power generation dispatch and losses.

Solution Number	Power Generation Dispatch						P_{loss} (MW)
	P1	P2	P3	P4	P5	P6	
1	251,5011	303,6430	503,1784	372,0273	302,5818	197,2887	130,2203
2	232,3758	279,3492	517,5958	354,5232	350,6707	198,0516	132,5663
3	215,4078	253,0333	527,6795	342,0363	402,2943	196,8399	137,2910
4	200,1823	225,1138	534,5338	332,0825	459,0936	193,8948	144,9007
5	251,3979	303,4700	504,0354	371,5787	302,5795	197,1201	130,1816
6	229,8066	275,6492	520,0211	352,2670	357,5224	197,7737	133,0399
7	210,9535	245,3253	530,6725	338,8414	417,3054	195,9489	139,0471
8	251,2550	303,2205	505,1916	370,9660	302,6004	196,8970	130,1305
9	226,4693	270,7152	523,1448	349,4187	366,6407	197,3463	133,7350
10	251,0526	302,8861	506,7861	370,1326	302,6197	196,5837	130,0609
11	249,8148	331,1466	400,6351	382,5055	342,3345	233,9569	140,3935
12	248,5790	327,9193	401,9170	380,2506	347,7469	234,1087	140,5215
13	247,3432	324,6639	403,1557	378,0802	353,1926	234,2439	140,6797
14	249,7516	331,5859	399,5224	382,6047	342,8721	234,2122	140,5489
15	248,5075	328,3034	400,8224	380,3194	348,3593	234,3659	140,6778
16	249,6916	332,0348	398,3792	382,7038	343,4214	234,4780	140,7088
17	249,5489	333,1441	395,6065	383,0695	344,6316	235,0907	141,0914
18	248,9144	331,4189	396,2803	381,8721	347,4974	235,1710	141,1541
19	249,5149	333,3956	394,9925	383,1269	344,9212	235,2277	141,1789
20	249,4543	333,8756	393,8175	383,2633	345,4490	235,4850	141,3445

6. Conclusion

In this paper, one of the recently introduced heuristic optimization methods, SA, has been discussed, developed and employed to treat the considered economic and environmental optimization problems of power system operation. The test system used to validate the proposed algorithm considered most of the practical aspects of the all-thermal generation systems. The transmission power losses are considered in the formulation of the problem. Various types of optimization functions were considered including single and multi-objective. By these simulated results, SA method provides superior result than previously reported method.

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