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Multi-objective PSO-TVAC for Environmental/Economic Dispatch Problem

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Abstract

In this paper a variant named time varying acceleration based particle swarm optimization (PSO-TVAC) proposed to enhance the solution of the combined environmental economic dispatch problem. The performances of the standard PSO are improved by adjusting dynamically the acceleration coefficient during process search to balance the exploitation and exploration capability. The proposed method is validated on IEEE 30-bus with quadratic cost function considering transmission losses and to 10 unit considering both valve point effect and total power losses. The simulation results are compared with those obtained by particle swarm optimization (PSO), no dominating sorting genetic algorithm (NSGA-II), and strength Pareto evolutionary algorithm (SPEA). The results demonstrate the efficiency of the proposed approach and show its simplicity and robustness to solve the environmental/economic dispatch problem.

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Keywords: Particle swarm, Multi-objective, OPF, PSO-TVAC, Environmental/economic dispatch, Fuel cost, Emission.

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1. Introduction

The economic dispatch problem (EDP) in a power system is to determine the optimal combination of power outputs for all generating units which will minimize the total cost while satisfying the constraints. When the environmental concerns that arise from the emissions produced by fossil-fueled electric power plants are combined with the EDP then the problem becomes Combined Economic and Emission Dispatch (CEED) problem [1].

The objective of emission dispatch is to minimize the total environmental degradation or the total pollutant emission due to the burning of fuels for production of power to meet the load demand. The emission function can be expressed as the sum of all types of emissions as NOx, SOx particulate materials and thermal radiation with suitable pricing for each pollutant emitted [2]. The multi-objective environmental/economic dispatch problem is to minimize

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two competing objective functions, fuel cost and emission, while satisfying several equality and inequality constraints [3].

The Particle Swarm Optimization (PSO) technique has been applied to solve power engineering optimization problems giving better results than classical methods. Many research results confirmed that the standard PSO fails to locate the global solution [4] when applied so solving multi objective optimization problems. For this pertinent reason a large number of modified and hybrid methods have been proposed by researchers to overcome the drawback associated to the standard methods such as: multi-objective evolutionary search strategies [5], multi-objective particle swarm optimization [6], fast e-constraint (EC) approach [5], strength Pareto evolutionary algorithm (SPEA)[3], multi objective based PSO [7], Differential evolution based dynamic decomposed strategy [8], no dominating sorting genetic algorithm (NSGA) [9], linear combination of different objectives as a weighted sum [10–11], NSGA-II [12], niched Pareto genetic algorithm (NPGA) [13], multi-objective stochastic search technique (MOSST) [14], tabu search [15], interactive fuzzy satisfying method (IFSM) [17], and Fuzzy clustering-based particle swarm optimization (FCPSO) [18, 32].

This paper proposes a multi-objective optimization strategy based PSO-TVAC for solution of economic environmental dispatch problem. This problem is formulated as a nonlinear constrained multi-objective optimization problem, in order to show the effectiveness of the proposed approach, two test systems are used in this paper IEEE 30-bus and 10 unit power system. Results obtained have been compared with those obtained from many metaheuristic techniques such as: non-dominated sorting genetic algorithm-II (NSGA-II) and strength Pareto evolutionary algorithm (SPEA), (SPEA-II) and (HPSO-GSA).

2. Background on PSO and PSO-TVAC

Particle Swarm Optimization (PSO) is a heuristic search methodology that tries to imitate the travels of a flock of birds aiming at finding food [23]. Unlike the mathematical methods for solving optimization problems, this algorithm does not need any gradient information about objective or error function and it can obtain the best solution independently [27]. The position of *ith* particle is changed by adding the velocity to the current position as follows:

$$v(t+1) = \omega.v(t) + (C_1.rand.\left(P_{best} - x(t)\right) \;+\; C_2.rand.\left(P_{gbest} - x(t)\right) \tag{1}$$

$$x(t+1) = x(t) + v(t+1) \tag{2}$$

Where $x(t)$ is the particle initial position, $v(t)$ is the initial velocity, $v(t+1)$ new particle velocity, $x(t+1)$ a new global solution, P_{best} best local solution, P_{gbest} best global solution,C_1 cognitive factor,C_2 social factor, ω inertial weights formulated as [28]:

$$\omega = (\omega_{max} - \omega_{min}) \times \frac{(iter_{max} - iter)}{iter_{max}} + \omega_{min} \tag{3}$$

Where *iter* is the current iteration number while $iter_{max}$ is the maximum number of iteration. In particle swarm optimization with time varying acceleration coefficients PSO-TVAC, the acceleration coefficient C_1, C_2 expressed as:

$$C_1 = \left(c_{1f} - c_{1i}\right) \times \frac{iter}{iter_{max}} + c_{1i} \tag{4}$$

$$C_2 = \left(c_{2f} - c_{2i}\right) \times \frac{iter}{iter_{max}} + c_{2i} \tag{5}$$

Where C_{1f} , C_{2f} ,C_{1i} , and C_{2i} are social acceleration factors and initial and final values of cognitive respectively

3. Problem objectives

3.1. Minimization of fuel cost

The objective of classical economic dispatch is the minimization of total generation cost while satisfying several constraints, mathematically formulated as follows:

$$F(P_g) = \sum_{i=1}^{n} a_i + b_i P_{g_i} + c_i P_{g_i}^2 \tag{6}$$

P_{gi}: Output power generation of unit *i*. a_i ,b_i ,c_i: Fuel cost coefficients of unit *i*,and this problem can be expressed as :

$$F(P_g) = \sum_{i=1}^{n}(a_i + b_n P_{g_i} + c_i P_{g_i}^2) + \left|e_i \, sin\left[f_i(P_{g_i} - P_{g_i}^{min})\right]\right| \tag{7}$$

Where e_i and f_i are two coefficients, required for introducing valve point effects.

3.2. Minimization of emission

The total (ton/h) emission $E(P_g)$ of atmospheric pollutants such as sculpture oxides SOx and nitrogen oxides NOx caused by fossil-fueled thermal units can be expressed as:

$$E(P_g) = \sum_{i=1}^{n} 10^{-2}(\alpha_i + \beta_i P_{g_i} + \gamma_i P_{g_i}^2) + \xi_i \, exp(\lambda_i P_{g_i}) \tag{8}$$

Whereα_i, β_i, γ_i, ζ_i, and λ_i are coefficients of the *ith* generator emission characteristics [26].

3.3. Minimization of fuel cost and emission

The Multi-objective combined economic and mission problem with its constraints can be mathematically formulated as a nonlinear constrained problem as follows:[1]

$$OF = \mathrm{u} \sum_{i=1}^{n} F(P_{g_i}) + (1 - \mathrm{u}) \sum_{i=1}^{n} E(P_{g_i}) \tag{9}$$

The solution of the problem is achieved by minimizing the objective function (*OF*), the fuel cost rate (*\$/h*) is shown with, $F(P_{gi})$ and NOx emission rate (*ton/h*) with $E(P_{gi})$.

3.4. Operational constraints and security limits

Power equality constraint in the system with transmission losses is expressed as follows:

$$\sum_{i=1}^{n} P_{g_i} - P_{load} - P_{loss} = 0 \tag{10}$$

Where P_{load} is the total load demand and P_{loss} is the total power loss in transmission lines. Since the power stations are usually spread out geographically, the transmission loss has to be taken into account. The commonly used method in power utility industry is the *B* coefficients method [19, 20], which is expressed as follows:

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{g_{i,n}} B_{i,j} P_{g_{j,n}} + \sum_{j=1}^{n} P_{g_{j,n}} B_{0j} + B_{00} \tag{11}$$

Where *B*, B_0 and B_{00} are all transmission loss coefficients, and *B* is a *n*x*n* matrix, B_0 is a 1 x n vector, B_{00} is a constant.The generation capacity constraints of the thermal generation units are shown in [21].

$$P_{g_i}^{min} \leq P_{g_i} \leq P_{g_i}^{max} \tag{12}$$

Where $P_{g_i}^{min}$ and $P_{g_i}^{max}$ are the minimum and maximum range of power loading limit for *nth* generator unit, respectively.

4. PSO-TVAC Algorithm

The mechanism search of the proposed variant based PSO applied to solving the combined fuel cost and environment problem is shown in Figure 1.

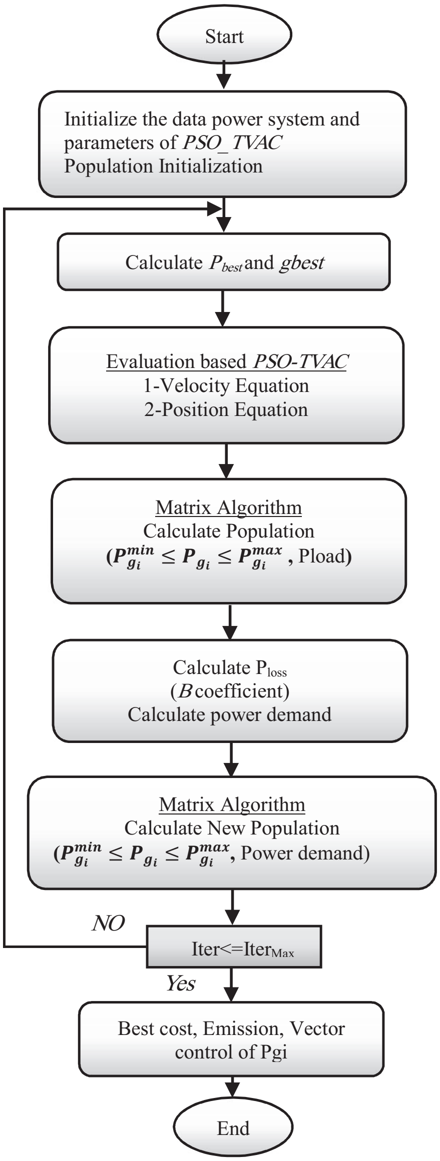

Fig. 1 Flowchart of PSO-TVAC

5. Case Studies and Numerical Results

5.1. Test system 1: IEEE 30-bus system

The proposed algorithm is applied to an IEEE 30-bus with 6 generating units, the load to be satisfied is 283.4 (MW). The single-line diagram of this system is shown in Fig. 2. The fuel cost rate coefficients, the NOx emission rate coefficients and the *B* coefficient matrix of the system are depicted in Appendix (Tables 7-8-9).

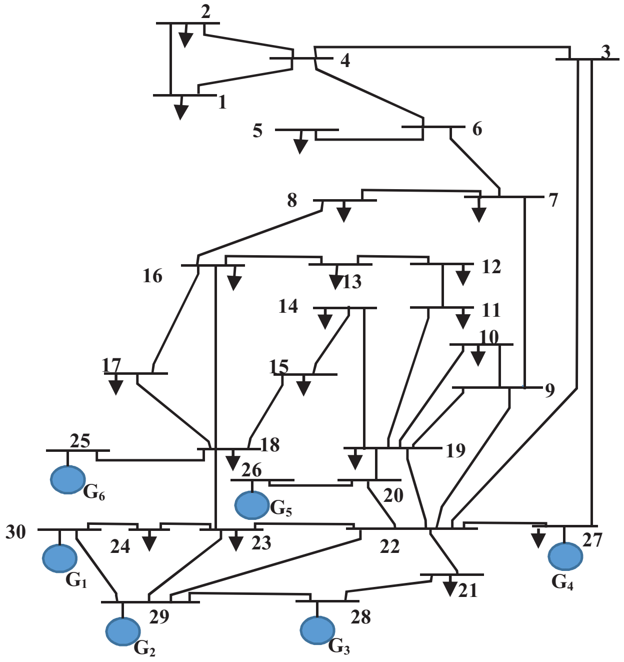

Fig. 2.Single-line diagram of IEEE 30-bus test system.

5.1.1 Case 1: optimization without considering power loss

In this first case, the losses associated to the IEEE 30-Bus test system are not considered. Table 1 shows the optimized control variables when fuel cost considered as the objective function, the best cost achieved is **600.1114** (*$/h*) which is better than results found using other methods as well illustrated in Table 1. The best control variables (active power generation) found considering the emission as an objective function are shown in Table 2. Figures 3-4 show the convergence characteristic of fuel cost and emission when optimized separately. Figure 5 shows the Pareto optimal solution when fuel cost and emission optimized simultaneously. It is important to note that the best solution obtained at reduced number of iteration.

5.1.2 Case 2: optimization considering power loss

This second test demonstrates the efficiency of the proposed PSO-TVAC in term of solution quality and convergence by considering the total transmission losses. The weight factor u increased from 0 to 1. The best total fuel cost achieved is **605.3435** (*$/h*) which is competitive with the results found using other methods

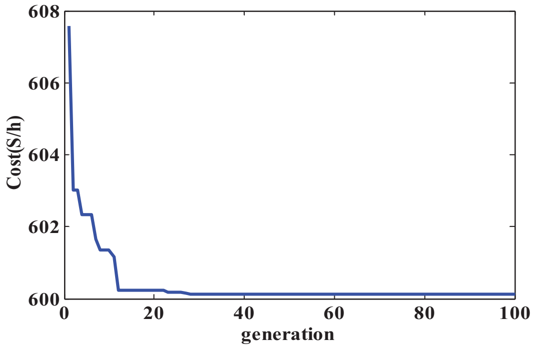

Fig. 3 Fuel cost optimization with PSO-TVAC: *case 1*

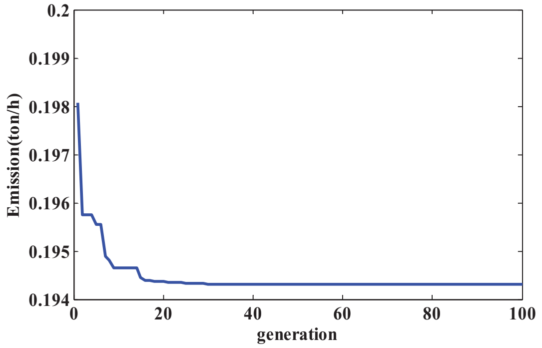

Fig. 4 Emission optimization with PSO-TVAC: *case 1*

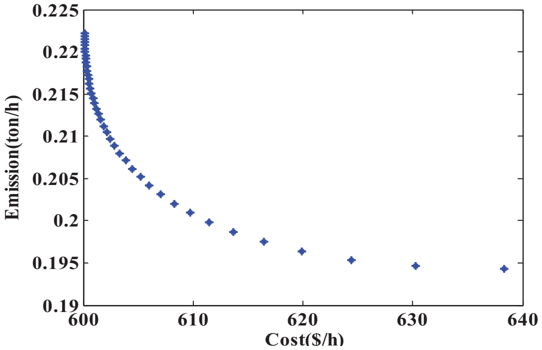

Fig. 5. Fuel Cost and Emission optimization with PSO-TVAC: *case 1*

Table 1 .Comparison of best solution for fuel cost minimization with different methods.

PGi (p.u)	PSO-TVAC	NSGA-II[22]	SPEA[8]	GSA[25]	HPSO-GSA[25]
P_{G1}	0.1098	0.1059	0.1009	0.0947	0.1096
P_{G2}	0.2999	0.3177	0.3153	0.2650	0.2998
P_{G3}	0.5244	0.5216	0.5400	0.5418	0.5243
P_{G4}	1.0161	1.0146	0.9903	0.9819	1.0162
P_{G5}	0.5242	0.5159	0.5336	0.5070	0.5243
P_{G6}	0.3597	0.3583	0.3507	0.4435	0.3598
P_{load} (pu)	2.8340	2.8340	2.8341	2.8339	2.8340
Cost($/h)	**600.1114**	600.155	600.22	601.06	600.11
EC(ton/h)	0.2222	0.2219	0.2206	0.2204	0.2221

Table .2. Comparison of the best solution for emission minimization with different methods.

PGi (p.u)	PSO-TVAC	NSGA-II [22]	SPEA[8]	GSA[3]	HPSO-GSA [25]
P_{G1}	0.4048	0.4074	0.4240	0.5000	0.4062
P_{G2}	0.4740	0.4577	0.4577	0.5643	0.4591
P_{G3}	0.5283	0.5389	0.5301	0.4435	0.5379
P_{G4}	0.3959	0.3837	0.3721	0.4429	0.3829
P_{G5}	0.5267	0.5352	0.5311	0.4818	0.5379
P_{G6}	0.5043	0.5110	0.5190	0.4014	0.5100
P_{load} (pu)	2.8340	2.8339	2.8340	2.8339	2.8340
Cost($/h)	637.6428	638.249	640.42	643.96	638.27
EC(ton/h)	**0.1943**	0.1942	0.1942	0.1942	0.1942

Table .3. Total fuel cost, total emission and transmission line loss values for some selected *u* values.

u	Cost($/h)	EC(ton/h)	P_{loss}(MW)
0.0	**645.9162**	**0.1943**	**3.4030**
0.1	621.2030	0.1979	2.5667
0.2	613.1420	0.2024	2.3434
0.3	609.2947	0.2066	2.2592
0.4	607.6092	0.2096	2.2328
0.5	606.4042	0.2129	2.2505
0.6	605.9322	0.2148	2.2380
0.7	605.6135	0.2167	2.2518
0.8	605.4442	0.2184	2.2636
0.9	605.3664	0.2199	2.2757
1.0	**605.3455**	**0.2211**	**2.2888**

Table. 4. Comparison of the optimal solution with different methods considering power loss.

Methods	Best total fuel cost			Best total emission		
	Cost ($/h)	EC (ton/h)	P_{loss} (MW)	Cost ($/h)	EC (ton/h)	P_{loss} (MW)
NSGA-II [30]	613.6759	0.2223	5.9500	648.7090	0.1942	6.0400
MNSGA-II+DCD [1]	608.1283	0.2199	3.4548	645.3998	0.1942	3.2894
MNSGA-II+DCD+CE [1]	608.1247	0.2198	3.4709	645.6472	0.1942	3.3173
DE [31]	608.0658	0.2193	3.4180	645.0850	0.1942	3.0403
PSO [7]	607.8400	0.2192	3.2900	642.9000	0.1942	3.0800
MBFA [32]	607.6700	0.2198	3.2600	644.4300	0.1942	3.2800
FCPSO [32]	607.7860	0.2221	3.3500	642.8964	0.1992	3.0900
MOPSO [29]	607.7900	0.2193	3.3300	644.7400	0.1942	3.0900
MO-DE/PSO [24]	606.0073	0.2208	2.5550	646.0243	0.1941	3.5350
MODA [16]	606.4160	0.2221	2.6034	643.5190	0.1942	3.3699
MMP-EC [5]	605.8363	0.2208	2.4600	646.2203	0.1942	3.6200
IABC [21]	605.4258	0.2209	2.3197	646.0455	0.1942	3.4815
IABC-LS [21]	605.4258	0.2210	2.3200	646.0455	0.1942	3.4815
ABCDP [21]	605.4259	0.2210	2.3191	646.0455	0.1942	3.4815
ABCDP-LS [21]	605.4258	0.2210	2.3200	646.0455	0.1942	3.4815
PSO-TVAC	**605.3455**	**0.2211**	**2.2888**	**645.9162**	**0.1943**	**3.4030**

5.2. Test system 2: 10 units considering valve point effect

A system with 10 generators with valve-point loading effects was studied in this third case. Total load demand of the system is 2000 (MW), coefficients for cost and emission objective functions, and matrix of power loss are depicted in Tables 10-11-12.The optimal repartitions of active power generations found in two cases (cost minimization and emission minimization) are shown in Tables 5-6. The total fuel cost and the total emission optimized using the proposed approach is relatively better and competitive compared to other methods.

Table. 5 Comparison of best solution for fuel cost minimization: *fuel cost* ($/h)× 10^5

PGi (MW)	PSO-TVAC	NSGA-II[24]	SPEA-2[24]	MODE[24]	PDE[24]
P_{G1}	54.9939	51.9515	52.9761	54.9487	54.9853
P_{G2}	79.8580	67.2584	72.8130	74.5821	79.3803
P_{G3}	104.1597	73.6879	78.1128	79.4294	83.9842
P_{G4}	98.5077	91.3554	83.6088	80.6875	86.5942
P_{G5}	80.1083	134.0522	137.2432	136.8551	144.4386
P_{G6}	82.5940	174.9504	172.9188	172.6393	165.7756
P_{G7}	299.8999	289.4350	287.2023	283.8233	283.2122
P_{G8}	339.9874	314.0556	326.4023	316.3407	312.7709
P_{G9}	469.9536	455.6978	448.8814	448.5923	440.1135
P_{G10}	469.9271	431.8054	423.9025	436.4287	432.6783
Cost ($/h)	**1.1105**	1.1354	1.1352	1.1348	1.1351
EC (ton/h)	4541.2	4581.00	4109.1	4124.90	4111.40

NR means not reported in the referred literature

Table. 6. Comparison of best solution for emission minimization: *fuel cost* ($/h)*$10^5$

PGi (MW)	PSO-TVAC	DE [24]	PSO [25]	GSA [25]	HPSO-GSA[25]
P_{G1}	54.9993	55.0000	55.00	55.00	44.40
P_{G2}	79.8849	80.0000	80.00	80.00	80.00
P_{G3}	80.7288	80.0000	109.47	120.00	89.32
P_{G4}	80.9341	81.0233	114.03	127.60	130.00
P_{G5}	159.9665	160.0000	50.00	98.78.68	50.00
P_{G6}	239.9995	240.0000	70.00	78.68	70.00
P_{G7}	299.9177	292.7434	300.00	300.00	300.00
P_{G8}	291.3522	299.1214	340.00	335.39	340.00
P_{G9}	394.5703	394.5147	470.00	372.51	465.03
P_{G10}	392.9594	398.6383	470.00	470.00	470.00
Cost ($/h)	1.1609	1.16400	NR	NR	NR
EC (ton/h)	**3910.5**	3923.40	3964.69	4066.66	3889.44

NR: means not reported in the referred literature

6. Conclusion

A flexible variant based PSO named PSO-TVAC algorithm is proposed to solving the combined environmental economic dispatch problem. The performances of the standard PSO are improved by adjusting dynamically the acceleration coefficient during process search to balance the exploitation and exploration capability. The robustness of the proposed variant has been tested with the standard IEEE 30-Bus with smooth cost function with and without power losses and to 10 units test system considering the valve point effect. It is observed from simulation results compared to many global optimization methods that the proposed simple PSO-TVAC planning strategy is capable to reduce the total fuel cost and emission at competitive values and at reduced number of iteration.

Appendix

Table. 7 Cost rate and active generation limits of the generation units [21]

	a_n	b_n	c_n	P_{min}	P_{max}
G_1	10	200	100	5	150
G_2	10	150	120	5	150
G_3	20	180	40	5	150
G_4	10	100	60	5	150
G_5	20	180	40	5	150
G_6	10	150	100	5	150

Table. 8. Emission rate curve coefficients [21]

	α_n	β_n	η_n	ζ_n	λ_n
G_1	$4.091e^{-2}$	$-5.554e^{-2}$	$6.490e^{-2}$	$2.0e^{-4}$	2.857
G_2	$2.543e^{-2}$	$-6.047e^{-2}$	$5.638e^{-2}$	$5.0e^{-4}$	3.333
G_3	$4.258e^{-2}$	$-5.094e^{-2}$	$4.586e^{-2}$	$1.0e^{-6}$	8.000
G_4	$5.326e^{-2}$	$-3.550e^{-2}$	$3.380e^{-2}$	$2.0e^{-3}$	2.000
G_5	$4.258e^{-2}$	$-5.094e^{-2}$	$4.586e^{-2}$	$1.0e^{-6}$	8.000
G_6	$6.131e^{-2}$	$-5.555e^{-2}$	$5.151e^{-2}$	$1.0e^{-5}$	6.667

Table. 9. Values of the **B** coefficients matrix [21]

$$[\mathrm{B}] = 10^{-2} \times \begin{bmatrix} 13.82 & -2.99 & 0.44 & -0.22 & -0.10 & -0.08 \\ -2.99 & 4.87 & -0.25 & 0.04 & 0.16 & 0.41 \\ 0.44 & -0.25 & 1.82 & -0.70 & -0.66 & -0.66 \\ -0.22 & 0.04 & -0.70 & 1.37 & 0.50 & 0.33 \\ -0.10 & 0.16 & -0.66 & 0.50 & 1.09 & 0.05 \\ -0.08 & 0.41 & -0.66 & 0.33 & 0.05 & 2.44 \end{bmatrix}$$

$$[\mathrm{B}_0] = 10^{-2} \times [-1.07 \quad 0.60 \quad -0.17 \quad 0.09 \quad 0.02 \quad 0.30]$$

$$[B_{00}] = 0.00098573$$

Table. 10. Fuel cost coefficients and active generation limits of ten unit system [24]

	P_{min}	P_{max}	a_n	b_n	c_n	d_n	e_n
G_1	10	55	1000.403	40.5407	0.12951	33	0.0174
G_2	20	80	950.606	39.5804	0.10908	25	0.0178
G_3	47	120	900.705	36.5104	0.12511	32	0.0162
G_4	20	130	800.705	39.5104	0.12111	30	0.0168
G_5	50	160	756.799	38.5390	0.15247	30	0.0148
G_6	70	240	451.325	46.1592	0.10587	20	0.0163
G_7	60	300	1243.531	38.3055	0.03546	20	0.0152
G_8	70	340	1049.998	40.3965	0.02803	30	0.0128
G_9	135	470	1658.569	36.3278	0.02111	60	0.0136
G_{10}	150	470	1356.659	38.2704	0.01799	40	0.0141

Table. 11. Emission coefficients of ten unit system [24]

	α_n	β_n	η_n	ζ_n	λ_n
G_1	360.0012	-3.9864	0.04702	0.25475	0.01234
G_2	350.0056	-3.9524	0.04652	0.25475	0.01234
G_3	330.0056	-3.9023	0.04652	0.25163	0.01215
G_4	330.0056	-3.9023	0.04652	0.25163	0.01215
G_5	13.8593	0.3277	0.00420	0.24970	0.01200
G_6	13.8593	0.3277	0.00420	0.24970	0.01200
G_7	40.2669	-0.5455	0.00680	0.24800	0.01290
G_8	40.2669	-0.5455	0.00680	0.24990	0.01203
G_9	42.8955	-0.5112	0.00460	0.25470	0.01234
G_{10}	42.8955	-0.5112	0.00460	0.25470	0.01234

Table. 12. Values of the *B coefficients* matrix for ten unit system [24]

$$[\mathrm{B}] = 10^{-6} \times \begin{bmatrix} 49 & 14 & 1515 & 16 & 1717 & 18 & 1920 \\ 14 & 45 & 1616 & 17 & 1515 & 16 & 1818 \\ 15 & 16 & 3910 & 12 & 1214 & 14 & 1616 \\ 15 & 16 & 1040 & 14 & 1011 & 12 & 1415 \\ 16 & 17 & 1214 & 35 & 1113 & 13 & 1516 \\ 17 & 15 & 1210 & 11 & 3612 & 12 & 1415 \\ 17 & 15 & 1411 & 13 & 1238 & 16 & 1618 \\ 18 & 16 & 1412 & 13 & 1216 & 40 & 1516 \\ 19 & 18 & 1614 & 15 & 1416 & 15 & 4219 \\ 20 & 18 & 1615 & 16 & 1518 & 16 & 1944 \end{bmatrix}$$

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