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Emission/Economic Load Dispatch Using Combination of Evolutionary Algorithms

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Abstract: This study presents an integrating Genetic Algorithm (GA) and Pattern Search (PS) approaches to solve the Combined Emission/Economic Dispatch (CEED) problems with multi-objectives have been developed. This integration will combine the strengths of GA and PS to solve this problem. The PS performance is highly dependent on the initial/starting point. To tackle this issue, GA was utilized to initiate the starting point for PS and to validate the obtained result of PS as well. The weighted multi-objective function with penalty factor is used in this study. The proposed weighting factor plays significant part on the problem solution. The proposed methodology considers operational power constraints of generating units, value-point loading ripple effects with non-convex characteristics and line losses as well for practical applications. The proposed integrating algorithms were intensively demonstrated, tested and verified on several cases. The obtained results prove high quality and effectiveness of proposed integrated GA-PS algorithm to solve CEED problems with reduced execution time.

Key words: Emission, evolutionary algorithms, load dispatch, mutli-objective function, Egypt

INTRODUCTION

Operating at absolute minimum cost can no longer be the only criterion for dispatching electric power due to increasing concern of the environmental considerations (Anonymous, 1991). Now a days, the Economic Emission Dispatch (EED) assumes a lot of significance to meet the clean energy requirements of the society while at the same time minimizing the cost of generation. Energy sources to produce mechanical power applied to the rotor shaft of generating units are of fossil fuels. This can cause a vast amount of carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions in which atmospheric pollution is created (Gent and Lamont, 1971; Talaq *et al.*, 1994).

The characteristics of emissions of different pollutants are different and are usually highly non-linear. The primary objective of this problem is to determine the most economic loadings of the generators such that the load demands in the intervals of the generation scheduling horizon can be met and the operation constraints of the generators are satisfied and minimizing the total emissions. Past decades, conventional optimization techniques such as Lagrangian Relaxation Method, Linear Programming, Quadratic Programming, the Gradient Method and Dynamic Programming have been successfully used to solve power system optimization problems (Talaq *et al.*, 1994; Lee and El-Sharkawi, 2008; Bansal, 2005; Zhu, 2009). Recently, there is an upsurge in the use of modern evolutionary computing techniques in the field of power system optimizations. The methods based on Artificial Neural Network (ANN) and Heuristic Search (HS) techniques based solution methodologies have been applied to solve emission economic dispatch problems. The Genetic Algorithm (GA) Method, Evolutionary Programming (EP), Evolution Strategy (ES), Tabu Search (TS) and Simulated Annealing (SA) are some of the well known Evolutionary algorithms (Lee and El-Sharkawi, 2008; Bansal, 2005; Zhu, 2009) and related fields such as Swarm Intelligence (Ant Colony Optimization (ACO), Bee Colony Optimization (BCO), Cat Swarm Optimization (CSO), Glowworm Swarm Optimization (GSO)/Fireflies Algorithm (FA) and Particle Swarm Optimization (PSO)) are suited to deal with the problem at hand because of their ability to find the solution near global optimal (Zhu, 2009).

Pao-La-Or *et al.* (2010), Pitono *et al.* (2009), Chaturvedi *et al.* (2008) and Thakur *et al.* (2006) PSO algorithm used to solve the problem of combined economic and emission dispatch. Penalty factors are defined which blendthe emission costs with the fuel costs. New and simple recursive approaches were applied and introduced to solve emission constrained dispatch problem (Muralidharan *et al.*, 2006; Balamurugan and Subramanian, 2007). An ANN based solution for CEED problem has been reported (Kumarappan *et al.*, 2002). The

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solution methodology using Hopfield Network Model had been suggested (King *et al*., 1995). GA and EP have been successfully applied to find the economic schedule of generation for CEED problems (Song *et al*., 1997; Guvenc, 2010; Basu, 2007; Venkatesh *et al*., 2003). SA is the stochastic optimization technique has been applied to find the solution of emission economic dispatch problems (Sasikala and Ramaswamy, 2010; Basu, 2005). An improved TS algorithm to Economic Emission Dispatch with Transmission Line Constraint was introduced (Senthil and Manikandan, 2010). Abido (2006, 2003), King *et al*. (2006) and Yokoyama *et al*. (1988) suggested and discussed the novel multi-objective to solve CEED problem subjected to variety of constraints. More details about GA have been presented by Goodman (2007) and Mitchell (1998). GA compared to traditional optimization methods can be listed as follows:

- GA seeks a number of candidate solutions in parallel and does not start from a single point
- GA uses probabilistic transition rules using GA operators rather than deterministic ones
- GA may use an encoding of the parameter set instead of the parameter itself
- GA does not require derivative information or other auxiliary knowledge except objective or fitness functions
- GA provides a high probability of finding the near global optimum
- GA is capable of coping with various problems and difficulties such as non-linearity, non-smoothness, discontinuity and non-convex characteristics

Due to these attractive properties, GA has become very popular for use in various power system optimization applications. A comprehensive review of direct and pattern search can be found by Audet and Dennis (2003), Kolda *et al*. (2003) and Al-Sumait *et al*. (2007) where a broader class of methods referred to as generating set search is described. The Hybrid PS Method that incorporates a GA in start process for initiating the starting point and at final stage for validating the obtained solution by PS Method has been introduced in this study.

This research presents the solution of the environmental economic dispatch problems using integration of GA and PS in order to help each other overcome their problems to obtain the best results in the shortest time. The contradicting bi-objectives are simultaneously minimized through the provision of the weighting factor and penalty factor. CEED has been proposed in the field of power generation dispatch which simultaneously minimizes both fuel cost and total emissions. When the emission is minimized the fuel cost may be unacceptably high or when the fuel cost is minimized the emission may be high. The environmental/economic dispatch involves the simultaneous optimization of fuel cost and emission objectives which are conflicting ones.

PROPOSED ENVIRONMENTAL ECONOMIC DISPATCH MODELLING

The mathematical model of the problem needs

Objective function: The Economic Load Dispatch (ELD) problem can be formulated mathematically as a constrained optimization problem with an objective function of the form as shown in Eq. 1. Objective function:

$$\text{Minimize: } FC_T = \sum_{i=1}^{N} FC_i(P_i) \tag{1}$$

And:

$$FC_i\ (P_i) = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

Where:

FC_T = The total generation cost
N = The total number of generating units
FC_i = The power generation cost function of the ith unit
P_i = The power of the ith generating unit
a_i-c_i = The fuel cost coefficients of the ith generating unit

The Cost Function (FC_i) should be modified to consider the valve-point effects as shown in Fig. 1. Typically, the valve point results in as each steam valve starts to open the ripples to be taken into account for the valve-point effects, sinusoidal functions are added to the quadratic cost functions as follows in Eq. 3:

$$FC_i\ (P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \times \sin\left(\left(f_i \times (P_{i,\min} - P_i)\right)\right) \right| \tag{3}$$

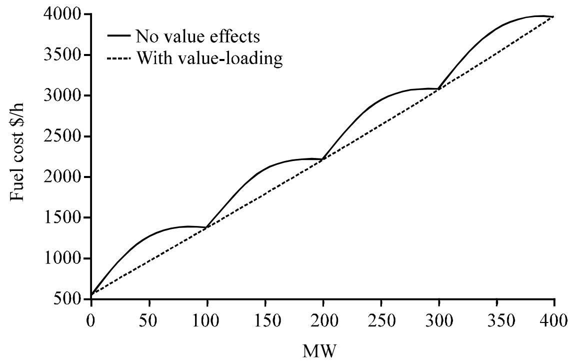

Fig. 1: Fuel cost function with and without valve-effects

Where:

$P_{i,min}$ = The minimum power output of generator (i)
a_i-c_i = The cost coefficients of generator (i)
e_i, f_i = Reflecting valve-point effects

On the other side, the pollutant emission dispatch problem can be described as the optimization of total amount of pollutant emission such as sulphur dioxide, SO_2 and nitrogen oxides, NO_x caused by burning of fuel in thermal defined by the following illustrated in Eq. 4 (Song *et al.*, 1997):

$$E_T = \sum_{i=1}^{N} \alpha_i P_i^2 + \beta_i P_i + \gamma_i + \xi_i e^{\tau_i P_i}) \qquad (4)$$

Where:

E_T = The total pollutant emission (kg/h)
P_i = The power output of generating unit i
α_i, β_i, γ_i, ξ_{i}, τ_i = Emission coefficients of unit i

Weighted sum CEED: To transform a multi-objective optimization problem into a single objective, weighted sum and utility method is often used. There are so many ways to construct the weighted sum function and there is not any easy guideline to choose which form is the best for a given problem. The choice of weighting coefficient is essentially to assign a preference order by the decision maker to the multi-objectives. The economic dispatch and emission dispatch are two different problems. Emission dispatch can be included in conventional economic load dispatch problems by adding an emission constraint into the problem. In this study, the two objectives can be converted into a single objective function (Muralidharan *et al.*, 2006; Balamurugan and Subramanian, 2007) by introducing a price penalty factor as illustrated in Eq. 5 as defined follows:

$$h_i = \frac{FC_i\,(P_i^{max})}{E_i\,(P_i^{max})} \qquad (5)$$

The price penalty factor blends the emission with fuel cost and is defined as the ratio between the maximum fuel cost and maximum emission of the corresponding generator. The bi-objective CEED problem is converted into single weighted optimization problem with introducing a price penalty factor h_i (Eq. 6):

$$\text{Min}(F_T) = \sum_{i=1}^{N} (W.FC_i + (1-W).h_i.E_i) \qquad (6)$$

where, the value of W ($0 \leq W \leq 1$) shows the importance of the two parts of the multi-objective function w.r.t. each other.

Equality and inequality constraints: The main constraints which are considered in this study are given equality constraint (Power balance constraint):

$$\sum_{i=1}^{N} P_i = P_{Dt} + P_{Loss} \qquad (7)$$

Where:

P_{Dt} = The total system load demand
P_{Loss} = The total line losses

P_{Loss} can be calculated using Eq. 8:

$$P_{Loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i^T B_{ij} P_j + \sum_{i=1}^{N} P_i B_{oi} + B_{oo} \qquad (8)$$

Where:

B_{ij}, B_{oi} and B_{oo} = Transmission line loss coefficients
P_i^T = Vector transpose of all generation plants net MW
B_{ij} = Square matrix of same dimension as P_i
B_{oi} = Vector of same length as P_i
B_{00} = Constant

Inequality constraints (Generation limits) which is shown as:

$$P_{i,\,min} \leq P_i \leq P_{i,\,max} \quad \text{for } i = 1, 2, ..., N \qquad (9)$$

where, $P_{i,\,min}$ and $P_{i,\,max}$ are the min/max power outputs of generator i. Finally, the mathematical model is summarized as:

$$\text{Min}\,\{FT\,(P_i, W)\}$$

Subjected to:

$$\sum_{i=1}^{N} P_i = P_{Dt} + P_{Loss}$$

$$P_{i,\,min} \leq P_i \leq P_{i,\,max}$$

PROPOSED INTEGRATION BETWEEN GA AND PS

GA is a stochastic optimization method which starts from multiple points to obtain a solution but it provides only a near global solution. In addition, it is not easy to regulate a GA convergence. Tuning global parameters such as population size, mutation probability and crossover probability has been the most recommended technique for control-ling premature convergence in the GA. A generally effective method for setting parameters has not yet been demonstrated. Ideal parameters are likely problem-dependent.

On the other hand, PS searches from a single point to obtain a solution. However, the solution obtained from PS is normally a local optimum solution. Therefore, in order to obtain a high quality solution the two parts method, comprising both GA and PS is proposed in this study. In the proposed method, after the specified termination criteria for the GA is reached using default option of MATLAB (http://www.mathworks.com) without any fine tune for parameters, PS is applied in the second part by using the solution from GA as an initial point to obtain a solution which is closer to the global solution. Finally, the solution obtained by PS is passed to GA for validation. The flow chart of the integration process is shown in Fig. 2.

The hybrid PS Method that incorporates a GA in start process for initiating the starting point and at final stage for validating the obtained solution by PS Method has been introduced in this study. The idea is to start GA with an initial random population with default settings (no need to consume lot of time for fine tuning of the GA parameters) to create new starting/initial point to be utilized by PS as the performance of PS is highly dependable on the starting point. Hence, the problem is tackled using both deterministic and stochastic approaches of different complexities. GA doesn't start the solution with a start point as PS does. GA starts to operate with more solutions compared to a starting population randomly created by taking determined objective function variables into consideration.

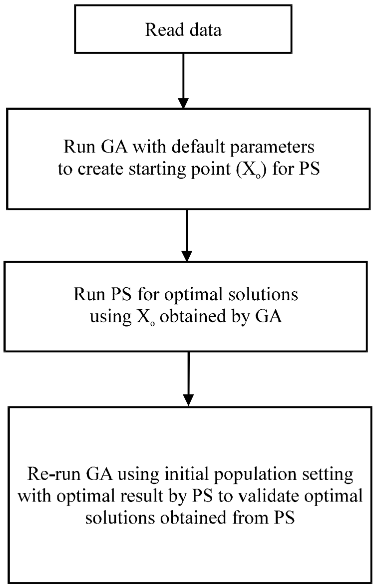

Fig. 2: Integration process of GA-PS

A set of MATLAB files, incorporated in the optimization toolbox, implementing the proposed PS and integrated GA-PS approaches have been used to solve various CEED problems with different study modes. Thus, the combined objective function for all test cases has been coded in MATLAB environment. The following parameters were needed for data input:

- Minimal and maximal power outputs of each unit
- B-matrix of line losses
- Coefficients of unit fuel cost function including coefficients of valve-point loading
- Emission coefficients
- Total load demand

The objective function, equality and inequality constraints were written in MATLAB m-files. The ranges for the variables were set in MATTLAB 7.12 Version release 2011a (http://www.mathworks.com).

NUMERICAL SIMULATIONS AND COMPARISONS

To verify the feasibility and efficiency of applying PS and integrated GA-PS to solve the environmental economic dispatch problem based on the proposed mathematical model and the proposed combination of GA and PS, several cases were tested compared and investigated. Among of these, two cases will be presented. The PS and GA-PS based algorithms are applied to solve the six-units with and without line losses (for sake of comparisons, neglecting effects of valve-loading) as illustrated in Case I. In Case II, the algorithms were applied to eleven-generator system with neglecting line losses. Simulations were carried out using Optimization Toolbox of MATLAB® 7.12 release 2011a version and executed on a LAPTOP with Processor Intel® Core i5 CPU 2.40 GHz with a 4.0 GB of RAM with 32-bit operating system.

Case I: 6-Generating Unit's System: Fuel cost coefficients and generation limits for each generating unit of the test system were given in Table 1. Table 2 shown pollutant emission coefficients of each generating unit.

Table 1: Fuel cost coefficients with capacity constrains neglecting ripple effects of valves

Units	a_i (\$/(MW^{2}h))	b_i (\$/(MWh))	c_i (\$/h)	$P_{i,min}$ (MW)	$P_{i,max}$ (MW)
G_1	0.15247	38.53973	756.79886	10	125
G_2	0.10587	46.15916	451.32513	10	150
G_3	0.02803	40.39655	1049.9977	35	225
G_4	0.03546	38.30553	1243.5311	35	210
G_5	0.02111	36.32782	1658.5696	130	325
G_6	0.01799	38.27041	1356.6592	125	315

The B-coefficients loss matrix:

$$B=1e^{-3}\times\begin{pmatrix} 0.1400 & 0.0170 & 0.0150 & 0.0190 & 0.0260 & 0.0220 \\ 0.0170 & 0.0600 & 0.0130 & 0.0160 & 0.0150 & 0.0200 \\ 0.0150 & 0.0130 & 0.0650 & 0.0170 & 0.0240 & 0.0190 \\ 0.0190 & 0.0160 & 0.0170 & 0.0710 & 0.0300 & 0.0250 \\ 0.0260 & 0.0150 & 0.0240 & 0.0300 & 0.0690 & 0.0320 \\ 0.0220 & 0.0200 & 0.0190 & 0.0250 & 0.0320 & 0.0850 \end{pmatrix}$$

The obtained results for the 6 Unit System using PS only and proposed GA-PS for power demand of 500 MW without and with line losses were given in Table 3 and 4, respectively. It showed that the both algorithms succeeded in finding a global optimal solution or near optimal solution for 3 modes of study for W = 0, W = 1 or W = 0.5 with relaxing all equality and inequality constraints. It is self-explanatory that the obtained results are matched by both methods. However, the execution time for the hybrid GA-PS is very completive and superior compared with using the PS only. PS algorithm is highly dependable on the starting point used to get the optimal or near optimal solution. As shown in Table 5 and 6 (CEED study mode with Weight = 0.5) in comparisons between obtained recent results (Muralidharan *et al*., 2006; Balamurugan and Subramanian, 2007; Guvenc, 2010; Sasikala and Ramaswamy, 2010) that both PS and proposed integrated GA-PS were succeeded to obtain very competitive solutions in very short time compared with SA that was able to get solution in 23.5 sec (Sasikala and Ramaswamy, 2010). The average execution

Table 2: Generator's emission data

Units	α_i (kg/(MW²h))	β_i (kg/(MWh))	γ_i (kg/h)
G_1	0.00419	0.327670	13.85932
G_2	0.00419	0.327670	13.85932
G_3	0.00683	-0.54551	40.26690
G_4	0.00683	-0.54551	40.26690
G_5	0.00461	-0.51116	42.89553
G_6	0.00461	-0.51116	42.89553

Table 3: Optimal scheduling of 6-generator by PS only and proposed GA-PS (No losses) with P_{Demand} = 500 MW

	Best fuel (W = 1)		Best emission (W = 0)		CEED (W = 0.5)	
Unit/Study mode	PS	GA-PS	PS	GA-PS	PS	GA-PS
P_{G1} (MW)	17.3990	17.3988	35.9318	35.9318	19.9768	19.9769
P_{G2} (MW)	10.0000	10.0000	35.9316	35.9318	14.8731	14.8730
P_{G3} (MW)	61.5468	61.5471	86.5684	86.5682	93.1161	93.1161
P_{G4} (MW)	77.9808	77.9810	86.5679	86.5682	90.1319	90.1319
P_{G5} (MW)	178.1666	178.1665	130.0002	130.000	143.6051	143.6048
P_{G6} (MW)	154.9068	154.9065	125.0001	125.000	138.2971	138.2972
Total FC ($/h)	27,004.1	27,004.1	27,327.9	27,327.9	27,092.6	27,092.6
Emission (kg/h)	281.919	281.918	255.346	255.346	261.134	261.134
Line losses (MW)	0.00	0.00	0.00	0.00	0.00	0.00
Execution time (sec)	4.632346	1.444066	2.738104	1.68603	3.246230	1.948214

FC = Fuel Cost

Table 4: Optimal scheduling of 6-generator by using PS only and integrated GA-PS (losses are considered) with P_{Demand} = 500 MW

	Best fuel (W = 1)		Best emission (W = 0)		CEED (W = 0.5)	
Unit/Study mode	PS	GA-PS	PS	GA-PS	PS	GA-PS
P_{G1} (MW)	19.4908	19.4910	38.1786	38.1785	21.7063	21.7063
P_{G2} (MW)	10.0000	10.0000	38.9995	38.9998	17.8420	17.8420
P_{G3} (MW)	72.6320	72.6317	88.0878	88.0876	95.1107	95.1107
P_{G4} (MW)	82.8055	82.8055	87.8587	87.8589	91.4427	91.4425
P_{G5} (MW)	175.1911	175.1910	130.0001	130.000	144.4177	144.4179
P_{G6} (MW)	149.7663	149.7666	125.5378	125.5378	138.7052	138.7053
Total FC ($/h)	27,443.2	27,443.2	27,755.2	27,755.2	27,519.4	27,519.4
Emission (kg/h)	281.751	281.752	260.912	260.912	266.736	266.737
Line losses (MW)	9.88579	9.8858	8.66256	8.66255	9.22467	9.22468
Execution time (sec)	4.077829	1.422702	2.622771	1.733114	2.869270	1.449194

Table 5: CEED comparison of fuel cost ($/h) for 6-Generator System (No losses)

P_{Demand}	Muralidharan *et al.* (2006); recursive	Balamurugan and Subramanian (2007); simplified recursive	Sasikala and Ramaswamy (2010); SA	Guvenc (2010); GA	Proposed PS	Proposed GA-PS
500	27,092.46	27,092.46	27,092.42	27,089.45	27,092.6	27,092.6
600	31,628.64	31,628.63	31,628.63	31,626.79	31,628.6	31,628.6
700	36,313.94	36,313.92	36,313.92	36,310.80	36,313.9	36,313.9
800	41,148.33	41,148.32	41,148.31	41,144.47	41,148.2	41,148.2
900	46,131.85	46,131.87	46,131.86	46,124.54	46,131.8	46,131.8
1000	51,264.49	51,264.47	51,264.41	51,262.31	51,264.5	51,264.5

Table 6: CEED comparison of emission (kg/h) for 6-Generator System (No losses)

P_{Demand}	Muralidharan *et al.* (2006); recursive	Balamurugan and Subramanian (2007); simplified recursive	Sasikala and Ramaswamy (2010); SA	Guvenc (2010); GA	Proposed PS	Proposed GA-PS
500	261.63	261.63	261.63	261.3307	261.134	261.134
600	338.99	338.99	338.99	338.4397	338.321	338.321
700	434.38	434.38	434.38	433.6409	433.510	433.510
800	547.80	547.80	547.79	546.7831	546.700	546.700
900	679.24	679.24	679.24	678.2906	677.892	677.892
1000	828.72	828.72	828.71	827.2612	827.086	827.086

Table 7: Generating units fuel cost coefficients (valve-effect coefficients are neglected) and generation operation limits

Units	a_i (\$/(MW^{2}h))	b_i (\$/(MWh))	c_i (\$/h)	$P_{i,min}$ (MW)	$P_{i,max}$ (MW)
G_1	0.00762	1.92699	387.85	20	250
G_2	0.00838	2.11969	441.62	20	210
G_3	0.00523	2.19196	422.57	20	250
G_4	0.00140	2.01983	552.50	60	300
G_5	0.00154	2.22181	557.75	20	210
G_6	0.00177	1.91528	562.18	60	300
G_7	0.00195	2.10681	568.39	20	215
G_8	0.00106	1.99138	682.93	100	455
G_9	0.00117	1.99802	741.22	100	455
G_{10}	0.00089	2.12352	617.83	110	460
G_{11}	0.00098	2.10487	674.61	110	465

Table 8: Emission coefficients of 11-Generator System

Units	α_I (kg/(MW^{2}h))	β_i (kg/(MWh))	γ_i (kg/h)
G_1	0.00419	0.67767	33.93
G_2	0.00461	0.69044	24.62
G_3	0.00419	0.67767	33.93
G_4	0.00683	0.54551	27.14
G_5	0.00751	0.40060	24.15
G_6	0.00683	0.54551	27.14
G_7	0.00751	0.40006	24.15
G_8	0.00355	0.51116	30.45
G_9	0.00417	0.56228	25.59
G_{10}	0.00355	0.41116	30.45
G_{11}	0.00417	0.56228	25.59

time to get solutions using a combination of GA-PS is 1.69 sec on average which is very low compared with (Sasikala and Ramaswamy, 2010).

Case 2: 11-Generating Unit's System no line losses: In order to demonstrate the efficiency and the robustness of the proposed algorithms, an 11-Generator System is considered with data given as shown in Table 7 and 8. The results of the proposed and other four methods are shown in Table 9-11 for best fuel costs in \$/h and emission rate in kg/h, respectively with relaxing all equality and inequality constraints. Figure 3 shows the mesh size throughout the convergence process of Integrated GA-PS. It is apparent that the mesh size decreases until the algorithm terminates in this case at a mesh size of 9.5367×10^{-7} in 2.62 sec in <100 iterations. However, the convergence with PS only, at mesh size of 9.5367×10^{-7} with execution time of 7.41 sec in 370 iterations as shown in Fig. 4. The normalized execution time of SA method reported by Sasikala and Ramaswamy (2010) is 28.45 sec for 11-Unit System which is very high compared to the proposed GA-PS hybrid approaches which is on average of 2.44 sec.

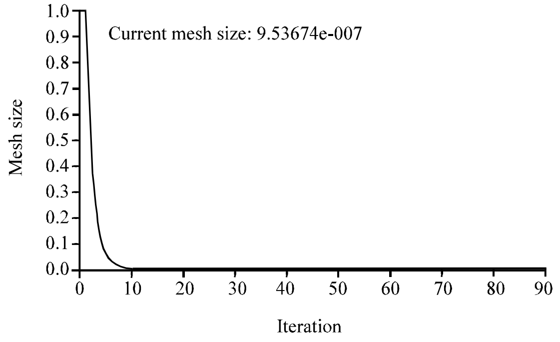

Fig. 3: Convergence graph for 11-units-case of 2500 MW power demand with GA-PS

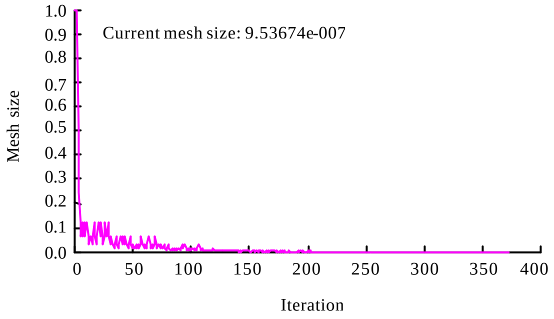

Fig. 4: Convergence graph for 11-units-case of 2500 MW power demand with PS only

It is obvious that the proposed methods produced very competitive solutions with a smaller search for 6 and 11 Generator Systems at the global optimal solution in very fast normalized execution time. Generally, both PS and proposed integrated GA-PS are able to obtain global or near global optimal solutions with competitive results. However, the execution time of proposed GA-PS is dramatically improved with this combination. For GA, no need to pay more effort on tuning the GA parameters as usual, only initial point is required for PS.

Table 9: Optimal scheduling of 11-generator by PS only and integrated GA-PS (No losses) with study mode of CEED

	$P_D = 1000$ MW		$P_D = 1500$ MW		$P_D = 2000$ MW	
Units	PS	GA-PS	PS	GA-PS	PS	GA-PS
P_{G1} (MW)	85.60571	85.60589	103.62813	103.62806	121.65040	121.65025
P_{G2} (MW)	76.67308	76.67290	88.70901	88.70881	100.74485	100.74481
P_{G3} (MW)	87.25848	87.25840	106.77278	106.77292	126.28760	126.28763
P_{G4} (MW)	78.49479	78.49472	126.17199	126.17216	173.84996	173.84921
P_{G5} (MW)	47.91502	47.91572	77.53466	77.53494	107.15409	107.15443
P_{G6} (MW)	79.32480	79.32483	125.74205	125.74242	172.16049	172.16013
P_{G7} (MW)	49.76554	49.76542	79.93089	79.93057	110.09568	110.09573
P_{G8} (MW)	129.60363	129.60347	201.41723	201.41799	273.23278	273.23184
P_{G9} (MW)	122.36940	122.37023	191.40796	191.40825	260.44515	260.44576
P_{G10} (MW)	119.60012	119.59961	200.94849	200.94816	282.29702	282.29663
P_{G11} (MW)	123.38944	123.38880	197.73680	197.73572	272.08197	272.08359
Total FC ($/h)	8,502.290	8,502.290	9,733.540	9,733.540	11,041.10	11,041.10
Emission (kg/h)	205.204	205.204	540.544	540.544	1,139.91	1,139.91
Execution time (sec)	7.607189	2.952258	7.784215	1.798952	8.265827	2.560709

Table 10: CEED comparison of fuel cost ($/h) for 11-Generator System (No losses)

P_{Demand}	Muralidharan *et al.* (2006); recursive	Balamurugan and Subramanian (2007); simplified recursive	Sasikala and Ramaswamy (2010); SA	Guvenc (2010); GA	Proposed PS	Proposed GA-PS
1000	8,502.29	8,502.29	8,502.30	8,501.85	8,502.29	8,502.29
1500	9,733.54	9,733.54	9,733.53	9,733.22	9,733.54	9,733.54
1750	10,377.77	10,377.77	10,377.78	10,377.01	10,377.8	10,377.8
2000	11,041.08	11,041.08	11,041.09	11,040.84	11,041.1	11,041.1
2500	12,424.94	12,424.94	12,424.94	12,423.77	12,424.9	12,424.9

Table 11: CEED comparison of emission (kg/h) for 11-Generator System (No losses)

P_{Demand}	Muralidharan *et al.* (2006); recursive	Balamurugan and Subramanian (2007); simplified recursive	Kumarappan *et al.* (2002); SA	King *et al.* (1995); GA	Proposed PS	Proposed GA-PS
1000	205.20	205.20	205.20	205.175	205.204	205.204
1500	540.54	540.54	540.54	539.493	540.544	540.544
1750	807.22	807.22	807.23	807.214	807.224	807.224
2000	1,139.91	1,139.91	1,139.91	1,138.279	1,139.91	1,139.91
2500	2,003.30	2,003.30	2,003.30	2,003.030	2,003.31	2,003.31

CONCLUSION

In this study, a weighting multi-objective function for environmental economic dispatching is proposed. The proposed objective function is optimized based on the proposed integration of GA and PS algorithms with comparative of the obtained results and time of calculations. The proposed solution algorithm is applied on 6 and 11 Generation Test Systems. The results showed that sets of suitable dispatch with respect to economic, emission or combined objectives can be efficiently found. Many others conditions and constraints were also observed and sustained such as load balance, generator's operation limits, valve-point loading effects and network line losses. The proposed algorithm has been demonstrated to perform well when applied to solve ELD, EmD and CEED problems.

PS proceeds with only one candidate solution all the time and therefore does not build up an overall view of the search space. Accordingly, high-quality results cannot be obtained by distinct algorithm within a reasonable time. Therefore, combining two or more algorithms in order to improve solution quality and reduce execution time may be achieved in most of optimization problems. The obtained results are compared with the results of other algorithms. The results show the ability of the proposed algorithm to reduce the running time compared with the other methods at the same level of accuracy.

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