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A Hybrid GA-PSO Approach Based on Similarity for Various Types of Economic Dispatch Problems

U. Guvenc, S. Duman, B. Saracoglu
Department of Electrical Education, Duzce University,
Duzce, Turkey, phone: +90 380 542 1133, e-mail: ugurguvenc@duzce.edu.tr
A. Ozturk
Department of Electrical-Electronic Engineering, Duzce University,
Duzce, Turkey, phone: +90 380 542 1133, e-mail: aliozturk@duzce.edu.tr

Introduction

The Economic Dispatch (ED) problem is one of the non-linear optimization problems in electrical power systems in which the main objective is to reduce the total power generation cost, while satisfying various equality and inequality constraints. Traditionally in ED problems, the cost function for generating units has been approximated as a quadratic function [1].

So far, many optimization methods have been used to overcome the ED problem. These methods can be classified as classical optimization, artificial neural networks and heuristic algorithms. Linear programming and quadratic programming are used as classical optimization methods [2–4]. Other approaches based on artificial neural networks and heuristic algorithms have been proposed to solve various ED problems. They include Hopfield neural network [5,6], improved Hopfield neural network [7], artificial neural network [8], improved ant colony search algorithm [9], particle swarm optimization algorithm [10], artificial immune [11], genetic algorithm [12] and particle swarm optimization with crazy particles [13]. Although these heuristic algorithms do not always guarantee the global best solutions, they can achieve a fast and near global optimal solution [13]. Genetic algorithm and particle swarm optimization (PSO) are the well-known examples of the modern heuristic algorithms, which can be used to solve nonlinear and non-continuous optimization problems. The PSO, was first motivated from the simulation of social behavior by Kennedy and Eberhart [14].

In this paper a new hybrid GA-PSO based on similarity method in order to solve the ED problems are proposed. The arithmetic crossover operator is used as crossover operator in the genetic algorithm. It can be defined to produce a new child as linear combination of two chromosomes. As randomly generated *a* coefficient is used to produce new child. In this method, a new approach for obtaining *a* coefficient is proposed benefitting from the similarity of parents chromosomes. The obtained results show that the proposed method has been applied successfully in various ED problems.

Classical Economic Dispatch Problem

Minimizing the total fuel cost of the thermal power plants while satisfying the demand power and power system constraints is aimed at to overcome the ED problem. The fuel cost effect is shown in Fig. 1.

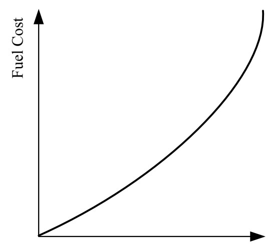

Fig. 1. Fuel cost effect

The ED problem can be formulated mathematically in (1) and (2):

$$F_T = Min\, f\left(FC\right), \tag{1}$$

$$FC = \sum_{i=1}^{n}\left(a_i \times P_i^2 + b_i \times P_i + c_i\right), \tag{2}$$

where a_i, b_i and c_i are the cost coefficients of the i^{th} generator. Generation output of each generator limit values have been given in (3) and (4):

$$P_i^{\min} \le P_i \le P_i^{\max}, \qquad i = 1, 2, ..., N, \tag{3}$$

$$D = \sum_{i=1}^{n} P_i - P_D = 0, \tag{4}$$

where D is power equilibrium and P_D represents the total demand power.

Economic Dispatch Problem with Valve point effects

The fuel cost characteristics of each generator are represented with the sinusoidal term added to the classical ED problem which models the valve point effect and the problem given in (5) and (6) [1]:

$$F_T = Min\, f\left(FC\right), \tag{5}$$

$$FC = \sum_{i=1}^{n}\left(a_i \times P_i^2 + b_i \times P_i + c_i + \left| e_i \times \sin\left(f_i \times \left(P_i - P_i^{\min} \right)\right)\right|\right), \tag{6}$$

where a_i, b_i and c_i are the cost coefficients and e_i, f_i are the constants of the valve point effects of the i^{th} generator. P_i^{min} and P_i^{max} represent the minimum limit and maximum limit on active power generation of each generator respectively:

$$P_i^{\min} \le P_i \le P_i^{\max}, \qquad i = 1, 2, ..., N, \tag{7}$$

$$D = \sum_{i=1}^{n} P_i - P_D - P_L = 0, \tag{8}$$

where D is power equilibrium, P_D and P_L represent the total demand power, and total transmission lines respectively. In this study, the transmission losses are ignored for the test system. The valve point effects are illustrated in Fig. 2.

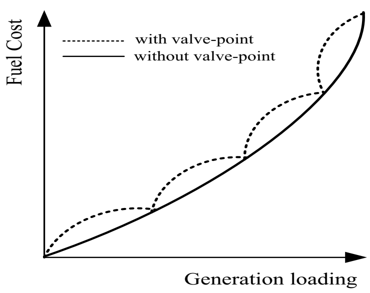

Fig. 2. The valve-point effect

Generator ramp-rate limits

The unit output cannot be adjusted instantaneously as soon as the load changes. Ramp-rate limits, i.e up-rate limit URi, down-rate limit DRi and previous hour generation Pi^o restrict the operating region of all the on-line units. When the generator ramp-rate limits are considered, the operating limits of the i^{th} generating unit are modified as follows [1]

$$Max\left(P_i^{\min}, P_i^o - DR_i\right) \le P_i \le Min\left(P_i^{\max}, P_i^o + UR_i\right). \tag{9}$$

Prohibited operating zones

The ED problem with prohibited zones minimizes the total fuel cost based on quadratic functions. This function presents the regions where the operation is not allowed and this can be represented as the inequality constraints given in (10). Here the power balance equilibrium (8) and limit values of each generator (7) are considered. The total transmission losses are given in (11):

$$P_i = \begin{cases} P_i^{\min} \le P_i \le P_{i1}^L, \\ P_{ik-1}^U \le P_i \le P_{ik}^L, \\ P_{izi}^U \le P_i \le P_i^{\max}, \end{cases} \tag{10}$$

where P_{ik}^L and P_{ik-1}^U are lower and upper bound of the k^{th} prohibited zone unit i and z_i the number of prohibited zones of unit i^{th}

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{oi} P_i + B_{oo}. \tag{11}$$

Proposed method

Evolutionary algorithms aim at reaching the global minimum or maximum value for the problems also wished to be overcome using the proposed method. They have some superiority over each other. The PSO provides a faster convergence rate than the GA early in the run. The PSO and GA are represented based upon the population characterizing a particular solution that is same for the both algorithms. A hybrid technique in order to utilize the effectiveness and uniqueness of these two algorithms can be implemented to achieve a high performance [15].

Grimaldi et al proposed a hybrid technique called as Genetical Swarm Optimization. In this hybrid algorithm, for each iteration, the population is divided into two parts and each part is evolved by its own operators with the two techniques respectively. These two parts are then recombined in the updated population, which is again divided randomly into another two new parts in the next iteration for another run of genetic or particle swarm operators [15].

In real coded genetic algorithm do not require coding and encoding procedures, therefore the computation time and complexity are highly reduced. Also, genetic operators such as crossover and mutation have significant impact on its performance. Michalewicz [16] described a arithmetic crossover operator. It linearly combines two parent chromosome vectors to produce two new children according to the following equations:

$$child1 = a * father + (1 - a) * mother, \tag{12}$$

$$child2 = (1 - a) * father + a * mother, \tag{13}$$

where a is a random weighting factor selected by the user. In this method, one child is created by the father and mother. The main drawback of this crossover operator is that a random crossover constant is used. In other words, in applications, there are always difficulties to select a perfect weighting factor. In this study, a constant is obtained from the similarity of parents chromosomes [17].

Similarity can be defined between two or more objects as problems associated. Similarity is an important concept that needs to be calculated in all fields of science. However, this concept can be calculated by the people as shareholding or observational, by machines is an issue that is very difficult to calculate. If we can make similar measurements, we can classify a new object into the group and predict the behavior of the new object. In this respect Nosofsky proposed the Generalized Context Model (GCM)

[18] where the probability was calculated as follows for x warning

$$P\left(C_k \mid x\right) = \frac{b_k h_k(x)}{\sum\limits_{l=1}^{K} b_l h_l(x)}, \tag{14}$$

where b_k is a response bias and $h_k(x)$ is given by a summed similarity between x and every stored exemplars of category C_k, [20]

$$h_k(x) = \sum_{n=1}^{N_k} \exp\left\{-d\left(x, x_n\right)^q\right\}, \tag{15}$$

where N_k is number of exemplars in category C_k. The γ parameter reflects the amount of determinism in responding. The quantity $h_k(x)$ can be interpreted as a measure of category similarity and therefore as a measure of evidence that stimulus x belongs to this category [20].

The variables in parent's chromosomes in a cluster are defined as follows:

$$m_k = \left\{x_i;\ i = 1\ \ to\ \ n\right\}, \tag{16}$$

$$f_k = \left\{y_i;\ i = 1\ \ to\ \ n\right\}, \tag{17}$$

where m_k is the mother and f_k is the father chromosomes. Unit load differences of mother and father chromosomes for i^{th} generator could be stated as follows

$$\Delta_i = (x_i - y_i), \qquad i = 1\ \ to\ \ n. \tag{18}$$

The generator distance between any two unit loads is calculated by Euclidean norm as

$$d_{f,m} = \frac{1}{\sqrt{n}} \cdot \left(\Delta_1^2 + \Delta_2^2 + ...\Delta_n^2\right)^{1/2}. \tag{19}$$

In GCM, the similarity of two unit loads could be calculated as

$$S_{f,m} = e^{\left(-d_{f,m}\right)}. \tag{20}$$

The $S_{f,m}$ value can be used instead of a coefficient in arithmetic crossover and varies between zero and one

$$\mathrm{a} = S_{f,m}\ \ (range\ 0\text{-}1). \tag{21}$$

Flow chart of the GA-PSO based on similarity is shown in Fig. 3.

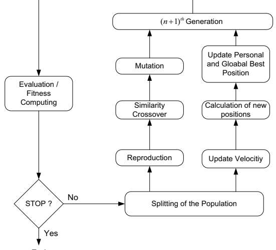

Fig. 3. Flow chart of the GA-PSO based on similarity

Economic dispatch problem with prohibited zones and ramp-rate limits

ED problem with prohibited operating zones and ramp-rate limits are included in this paper. The second test case has 6-generating units [13] and a total load of 1263 MW. All the units have prohibited zones and ramp-rate limit constraints. Power losses are considered for this system using the B-matrix from [13].

Table 1. Generator operating limits and cost coefficients of the test system

Unit	$Pmin_i$	$Pmax_i$	a_i	b_i	c_i
1	100	500	0.0070	7	240
2	50	200	0.0095	10	200
3	80	300	0.0090	8.5	220
4	50	150	0.0090	11	200
5	50	200	0.0080	10.5	220
6	50	120	0.0075	12	190

Table 2. B-loss coefficients of the test system

$B_{i,j}=10^{-3}$	1.7	1.2	0.7	-0.1	-0.5	-0.2
	1.2	1.4	0.9	0.1	-0.6	-0.1
	0.7	0.9	3.1	0.0	-1.0	-0.6
	-0.1	0.1	0.0	2.4	-0.6	-0.8
	-0.5	-0.6	-1.0	-0.6	12.9	-0.2
	-0.2	-0.1	-0.6	-0.8	-0.2	15.0
B_{0i}=	-0.3908	-0.1297	0.7047189	0.0591	0.2161	0.6635
B_{00}=						56.0

Table 3. Prohibited zones and ramp-rate limits data of the test system

Unit	P_i^o	URi	DRi	Prohibited zone	
1	440	80	120	[210,240]	[350,380]
2	170	50	90	[90,110]	[140,160]
3	200	65	100	[150,170]	[210,240]
4	150	50	90	[80,90]	[110,120]
5	190	50	90	[90,110]	[140,150]
6	110	50	90	[75,85]	[100,105]

Table 4. Generator loading, loss, power output and fuel cost determined by different methods

Generator	PSO	PSO_crazy	RGA	Proposed Method
Pg1	469.9415	464.5764	420.2342	431.5408
Pg2	175.5558	177.8071	199.4412	184.272
Pg3	246.5108	265.0000	263.7234	259.7322
Pg4	138.7732	120.9708	120.0030	138.8306
Pg5	152.3809	156.7055	167.2319	168.6130
Pg6	92.1599	90.6358	105.1250	92.4211
Total loss	12.3222	12.6956	12.7588	12.4093
Total cost ($/h)	15451.3	15449.3	15461.3	**15446.1**

A power system with 6 generators data are given in Table 1, 2 and 3. In this system, PSO, PSO crazy, RGA and hybrid GA-PSO methods were used in economic dispatch. According to the results obtained using the hybrid GA-PSO method for economic dispatch is more advantageous than the other methods. In power system with six generators, if economic dispatch is realized by using the hybrid GA-PSO, a gain of fuel costs can be achieved in total. Also the total line loss is decreased.

Economic dispatch with valve point effects

This test case consists of 13-generating units with quadratic cost function combined with the effects of valve point loading. The units data (upper and lower bounds) along with the cost coefficients for the fuel cost (a,b, c, e and f) for the 13 generators with valve-point loading are given in [1].

Table 5. Generator operating limits and cost coefficients of the test system

Unit	$Pmin_i$	$Pmax_i$	a_i	b_i	c_i	e_i	f_i
1	0	680	0.00028	8.10	550	300	0.035
2	0	360	0.00056	8.10	309	200	0.042
3	0	360	0.00056	8.10	307	150	0.042
4	60	180	0.00324	7.74	240	150	0.063
5	60	180	0.00324	7.74	240	150	0.063
6	60	180	0.00324	7.74	240	150	0.063
7	60	180	0.00324	7.74	240	150	0.063
8	60	180	0.00324	7.74	240	150	0.063
9	60	180	0.00324	7.74	240	150	0.063
10	40	120	0.00284	8.6	126	100	0.084
11	40	120	0.00284	8.6	126	100	0.084
12	55	120	0.00284	8.6	126	100	0.084
13	55	120	0.00284	8.6	126	100	0.084

Table 6. Generator loading and fuel cost determined by the proposed method

Generator	Generator production
Pg1	538,5831
Pg2	224,4069
Pg3	150,0666
Pg4	109,8827
Pg5	109,8683
Pg6	109,8697
Pg7	109,9566
Pg8	109,8623
Pg9	110,0375
Pg10	77,3991
Pg11	40,0015
Pg12	55,0103
Pg13	55,0555
$\sum Pgi$	1800 MW
Total Cost ($/h)	**17968,5034**

A power system with 13 generators data are given in Table 5. In this power system economic dispatch is realized by using the CEP, FEP, MFEP, IFEP, PS, and hybrid GA-PSO methods. Economic dispatch results are given in Table 7. When economic dispatch is done by using the hybrid GA-PSO, in both total fuel costs and reducing the total line losses significant gains can be achieved.

Table 7. Comparison of proposed method

Evolution Method	Total Cost ($)
CEP	18048.21
FEP	18018.00
MFEP	18028.09
IFEP	17994.07
PS	17969.17
Proposed Method	**17968.50**

Economic dispatch with only fuel options

A power system with 18 generators data are given in Table 8 [19]. This power system is loaded with different load demands that are given in Table 9. In this power system economic dispatch is made by using different methods and loads. Economic dispatch results are given in Table 10. The solution presented in this paper based on a hybrid GA-PSO to solve various ED problems. If economic dispatch is done by using proposed method, total fuel costs significant gains can be achieved.

Table 8. Generator operating limits and cost coefficients of the test system

Unit	Pmini	Pmaxi	a_i	b_i	c_i
1	15,00	7	85,74158	22,45526	0,602842
2	45,00	7	85,74158	22,45526	0,602842
3	25,00	13	108,9837	22,52789	0,214263
4	25,00	16	49,06263	26,75263	0,077837
5	25,00	16	49,06263	26,75263	0,077837
6	14,75	3	677,73	80,39345	0,734763
7	14,75	3	677,73	80,39345	0,734763
8	12,28	3	44,39	13,19474	0,514474
9	12,28	3	44,39	13,19474	0,514474
10	12,28	3	44,39	13,19474	0,514474
11	12,28	3	44,39	13,19474	0,514474
12	24,00	3	574,9603	56,70947	0,657079
13	16,20	3	820,3776	84,67579	1,236474
14	36,20	3	603,0237	59,59026	0,394571
15	45,00	3	567,9363	56,70947	0,420789
16	37,00	3	567,9363	55,965	0,420789
17	45,00	3	567,9363	55,965	0,420789
18	16,20	3	820,3776	84,67579	1,236474

Conclusions

This paper introduces a new approach based on similarity a hybrid GA-PSO to solve various economic dispatch problems of the power system. It has been applied to 6, 13 and 18 generators test system. The results have been compared to Ref. [13], [1] and [19]. The results in various type economic dispatch problems demonstrate the feasibility and effectiveness of the proposed approach in minimizing cost of the generation. As a result, it has been shown that the proposed method improves the convergence and performs better when compared with the [1, 13, 19].

Table 9. Generator loading and fuel cost determined by the proposed method for different load demands

Generator	POWER OUTPUT		
	80% P	**70% P**	**365 MW**
Pg1	15,0000	15,0000	15,0000
Pg2	45,0000	43,7778	44,8494
Pg3	25,0000	25,0000	25,0000
Pg4	25,0000	25,0000	24,9994
Pg5	25,0000	25,0000	25,0000
Pg6	3,9976	3,0000	5,6032
Pg7	3,2610	3,0000	6,1208
Pg8	12,2800	12,2800	12,2800
Pg9	12,2800	12,2800	12,2800
Pg10	12,2800	12,2800	12,2800
Pg11	12,2800	12,2800	12,2800
Pg12	20,6582	13,7121	20,8718
Pg13	3,0000	3,0000	3,4000
Pg14	30,0935	22,2356	31,9164
Pg15	30,7728	22,7679	36,1615
Pg16	33,5814	24,9148	36,2779
Pg17	33,9489	24,7425	36,3579
Pg18	3,1426	3,0000	4,3280
Total cost ($/h)	**23859,0012**	**20390,2625**	**25451,5661**

Table 10. Comparison of proposed method for different load demands

Demand	y-iteration	Binary GA	Real GA	Proposed Method
80% P	23861,58	23980,24	23861,58	**23859,0012**
70% P	20393,43	20444,68	20396,39	**20390,2625**
365 MW			25768,57	**25451,5661**

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Economic dispatch problem is an optimization problem where objective function is highly nonlinear. In this paper, an efficient method based on hybrid genetic algorithm- particle swarm optimization (GA-PSO) for economic dispatch (ED) problem is proposed. In the proposed method, children created by using similarity measurement between mother and father chromosomes relationship. The feasibility of the proposed approach is demonstrated for solve various types of economic dispatch (ED) problems in power systems such as, economic dispatch with valve point (EDVP) effects, the ED of generators with prohibited operating zones and ED with only fuel options and it is compared in the recent literature. The study results show that the proposed approach is more efficient in finding higher quality solutions in various type ED problems. Ill. 3, bibl. 20, tabl. 10 (in English; abstracts in English and Lithuanian).

U. Guvenc, S. Duman, B. Saracoglu, A. Ozturk. Hibridinio genetinio algoritmo tyrimas sprendžiant įvairias svarbias ekonomines problemas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 2(108). – P. 109–114.

Svarbios ekonominės problemos yra traktuojamos kaip labai netiesinės funkcijos. Pasiūlytas hibridiniu genetiniu algoritmu paremtas efektyvumo metodas ekonominėms problemoms spręsti. Metodas sudarytas pasitelkiant vaikų panašumo į tėvus kriterijus. Pateikta keletas palyginamų problemos sprendimo būdų. Il. 3, bibl. 20, lent. 10 (anglų kalba; santraukos anglų ir lietuvių k.).