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ECONOMIC DISPATCH BY USING DIFFERENT CROSSOVER OPERATORS OF GENETIC ALGORITHM

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ABSTRACT

The great advances in technology and industry have brought about an increase in the demand for energy in electrical power systems. In order to meet this increased demand, planning the operation of power systems and optimum operation of those systems are required. To obtain it, optimal power flow, reactive power optimization and solutions of the economic dispatch problem are required. The problem of Economical Dispatch (ED) is one of the limited non-linear optimization problems of electrical power systems. Operation of generators with minimum cost by being held in certain limit values is required. Intuitional methods resulting in better conclusions have been used in solving this complicated non-linear problem so far. In this study, the conclusions obtained on conditions with line loss and without line loss of 3 and 6 switchboards with thermal fuel were compared with each other by using different crossover operators of genetic algorithm (GA).

Keywords- *Economic Dispatch, Genetic Algorithm, Crossover Operators, Power Systems*

1. INTRODUCTION

Nowadays, advances in technology cause more energy demand in power systems and make these systems more complicated. Operation of power systems on optimal conditions and planning of it are required due to the increased energy demand and decline in energy sources. The ED problem, one of the non-linear optimization problems in electrical power systems, has an important place in the economical operation of the power system. While the energy capacity and reliability of the power system are boosted, the production cost is decreased. In the process of minimizing the production costs of generators in order to meet the power demand in power systems, powers produced by generators are required to be in the optimal value between maximum and minimum values. So far, too many optimization methods have been used in the solution of ED problem. These methods can be classified as classical optimization, artificial neural networks and heuristic algorithms. In the solution of ED problem, linear programming and quadratic programming are used as classical optimization [1,2]. Such classical optimization methods are highly sensitive to staring points and often converge to local optimum or diverge altogether. Linear programming methods are fast and reliable, but have a

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drawback associated with the piecewise linear cost approximation. Non-linear programming methods have known problems of convergence and algorithmic complexity [3]. Methods based on artificial intelligent techniques, such as artificial neural network have been applied successfully [4,5]. The Park et al. presented the economic load dispatch for piecewise quadratic cost functions using the Hopfield neural network [6]. Yalcinoz et al. [7] was solved to constrained economic dispatch problem with prohibited operating zones using Hopfield neural network. Lee et al. [8] applied the adaptive Hopfield neural network in the economic dispatching of electric power systems. Lin et al. [9] solved the nonconvex economic dispatch problem by using integrated artificial intelligence. Besides artificial neural network approach, heuristic methods are also used in the solution of economic dispatch problem [10-15]. Mantawy et al. [16] solved the problem of economic dispatch by using genetic algorithm, simulated annealing and tabu search algorithms. Yalcinoz et al. [17] applied a genetic algorithm based on arithmetic crossover and He Da-kua et al. [18] hybrid genetic algorithm in the economic dispatch problem of power systems. Chen end Wang [19] utilized Marginal Rate of Substitution Decision Approach to solve ED problem. Song and Xuan [20] genetic algorithm based penalty function method have been used to solve combined heat and power ED problem. Khamsawang and Jiriwibhakorn [21] utilized differential evolution algorithm and Younes et al. [22] utilized genetic algorithm and matpower to solve ED problem.

In Turkey the solution of ED problem was made by using Lagrange function in 380 kV, 14 bus, 6 thermal power plants [23]. In this study, the ED problem, one of the optimization problems, was analyzed by using different crossover operators of GA that is among the intuitional methods. As an example, data of power systems in the studies conducted in ref. [23] and [24] was taken into consideration. The results obtained by the applied method were compared to the results in ref. [23] and [24]. In this study, it was seen that genetic algorithm, which is among intuitional methods, yields more reliable and better results in solving the economic dispatch problem, one of the non-linear problems in power systems, compared to the conventional methods. It can be applied successfully in solving the economic dispatch problem both in Turkey and the world.

2. ECONOMIC DISPATCH

Generators work between limit values. These values vary depending on the demand load in electric power systems. ED tries to minimum cost of fuel in the power systems. The economic dispatch determines its optimal sharing in accordance with demanded load for each unit at intervals of 3 and 5 minutes [17]. Figure 1 shows N thermal-generating units connected to a single bus-bar serving a received electrical load P_{Load}. The mathematical terms when minimizing the production cost of the thermal power plants of the system in economic load dispatch are given as follows:

$$Min\sum_{i=1}^{N} F_i\left(P_{G_i}\right) = Min\sum_{i=1}^{N}\left(a_i + b_i P_{G_i} + c_i P_{G_i}^2\right) \quad (1)$$

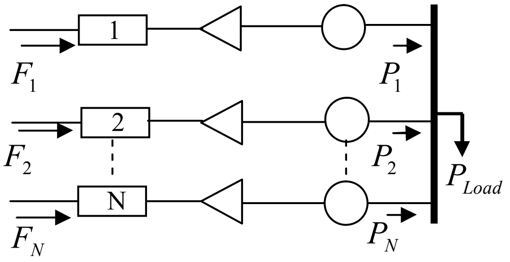


Figure 1. N thermal units committed to serve a load of

Where a_i, b_i and c_i are the cost coefficients of the i-th generator and N is the number of generators committed to the operating system. P_i is the power output of the i-th generator. The output power of generator must be higher than the minimum active power value in the determined limit values or equal to it or it must be lower than the maximum active power value or equal to it.

$$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max} \quad for \;\; i=1,...,N \qquad (2)$$

Where

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \qquad (3)$$

$$D = \sum_{i=1}^{N} P_{G_i} - P_D - P_L = 0 \qquad (4)$$

Where D is power equilibrium and P_L represents the transmission losses. B_{ij} represents coefficients of losses.

3. EMPLOYING THE GENETIC ALGORITHM

Genetic algorithms are search algorithms based on the process of biological evolution. The flow diagram of GA shows in Figure 2. GA is a widely used method in the solution of non-linear optimization problems regarded as very hard among the conventional optimization methods based on genetic logic [25]. GA doesn't start the solution with a start point as conventional optimization methods do. GA starts to operate with more solutions compared to a starting population randomly created by taking determined fitness function (FF) variables into consideration. Then it tries to turn the solutions into an optimum solution by using genetic operators (elitism, selection, crossover, mutation) [26]. Thanks to this, better ones are selected among many solutions and worse ones are eliminated. The starting population is made haphazardly as a result of the variables coding.

The variables can be coded by different ways such as duality coding, permutation coding, value coding, and tree coding. The structure of the problem dealt with is critically important in choosing the coding type. In this study, variables form the population by being coded as the combinations of 0 and 1 genes. The FF values are computed for each line of the population. Taking the FF values into consideration, a new population is created as a result of the usage of GA's operators. The FF values are computed in every new population. The ones that give the best results are taken into account. These operations continue repeatedly as many as the numbers of generations determined in GA. Therefore, obtaining the desired result is tried by making flourishing solutions with GA [27].

3.1. Forming the fitness function

Optimum operation values of the generators will be found by solving the ED problem using GA in the system given in Figure 1. For this, the goal function (GF) and constraint functions in this problem are given as follows:

Goal Function

$$GF = Min\sum_{i=1}^{N} F_i\left(P_{G_i}\right) = Min\sum_{i=1}^{N} a_i + b_i P_{G_i} + c_i P_{G_i}^2 \qquad (5)$$

Constraint Functions

$$CF = \sum_{i=1}^{N} P_{G_i} - P_D - P_L = 0 \qquad (6)$$

$$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max} \quad for \;\; i=1,...,N \qquad (7)$$

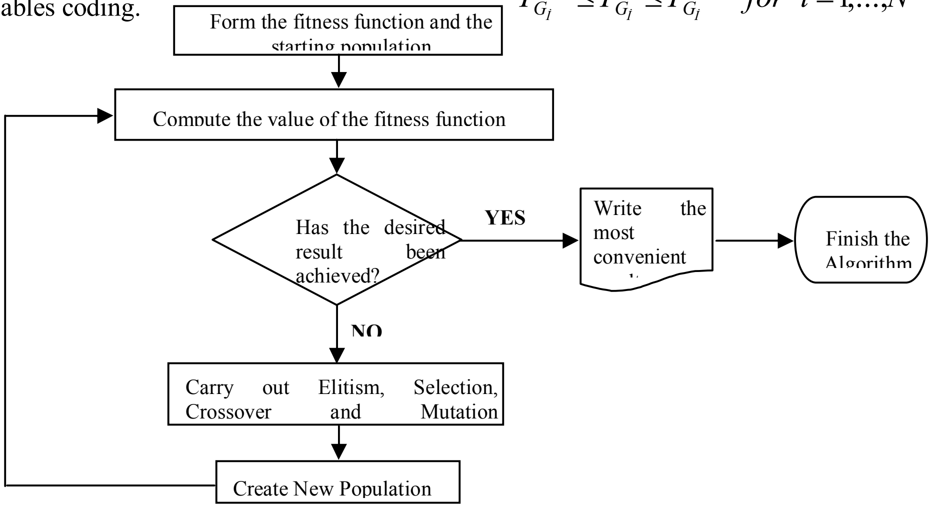


Figure 2. The flow diagram of GA

GA operates as an unrestricted optimization method. Restricted optimization problem, in case of the negligence of the constraints, is turned into an unrestricted optimization by being disciplined with PF. In this way, AF values will be held in certain limits. While generators are being held between minimum and maximum limit values, if the power balance is not obtained, the inconvenient values will be eliminated in the solution space by exposing the aim function to the penalty function. The total constraint function is squared in order not to prevent achieving the result by changing brand and in respect of the problems' condition it is multiplied by an appropriate coefficient. In this study, the (a) coefficient is taken as 25. Penalty function is given as follows:

$$PF = a \times (CF)^2 \tag{8}$$

Fitness function is given as follows:

$$FF = Min \sum_{i=1}^{N} F_i \left(P_{G_l}\right) + PF \tag{9}$$

In fitness function, the production values of generators are regarded as variables and must be held between certain limit values.

3.2. Variables coding

The starting population represents a gene pool whose all elements are formed at random. There are different coding methods in the formation of this gene pool and binary number system is preferred in this study. In this system, the genes consist of the elements, 0 and 1. In fitness function, no matter how many variables there are, the coded genes of those variables according to the variables' bit numbers form individuals by standing side by side in the population. The bit numbers of the variables to be coded are given in Table 1. The bit numbers of the variables [28] are computed as the following:

$$2^{\lambda n} \geq \frac{P_{G_l}^{\max} - P_{G_l}^{\min}}{\varepsilon} + 1 \tag{10}$$

Table 1. Bit numbers of variables to be coded

Variables	**Lower limit**	**Upper limit**	ε	**Bit numbers**
P_{G_1}	318	1412	0.05	15
P_{G_2}	150	600	0.05	15
P_{G_3}	210	990	0.05	15
P_{G_4}	110	420	0.05	15
P_{G_5}	140	630	0.05	15
P_{G_6}	140	630	0.05	15

In this study, each variable in GA forms an individual in the population by being 90 bits in the aggregate from 15 bits. Also, it starts the solution with a starting population formed by a computer program randomly with 90 bits, 100 lines, and codes whose bit values are 0 and 1 in the aggregate. After the starting population is formed, each individual is written in its place in the FF by turning the binary number system it is coded with to decimal system. The GA operators: elitism, selection, crossover and mutation degrees form a new population in each generation.

3.3. GA Operators

100 fitness values are calculated by turning every individual of the population in binary number system to decimal system. Two individuals from those that give the lowest value are selected by elitism and the other individuals are selected by tournament method among themselves and then crossover and mutation operators are applied. The crossover operator is the process in which prospective new individuals are created by the gene exchange of selected individuals. In this study, the ED problem has been solved by using different crossover operators.

3.3.1 One point crossover (OPX)

A random number is produced in one point crossover operator. If this number is lower than the determined crossover rate, two individuals will be selected from tournament method solution space. Between the selected two individuals, new individuals are produced by making replacement between these individuals from the point in the value of the random number [27, 29]. One point crossover is shown in Table 2.

Table 2. One point crossover

Parent 1	1 0 1 0 1 1 1 ... 1 1 0 1 0 1 0 1 0 1
Parent 2	0 1 0 1 1 0 0 ... 0 1 1 0 0 1 0 1 1 1
Candidate Parent (Child 1)	1 0 1 0 1 1 1 ... **0 1 1 0 0 1 0 1 1 1**
Candidate Parent (Child 2)	0 1 0 1 1 0 0 ... **1 1 0 1 0 1 0 1 0 1**

3.3.2. Two point crossover (TPX)

Two random numbers are produced in this crossover operator. If these numbers are lower than the determined crossover rate, two individuals that was selected by tournament method will be selected. New individuals are produced by making replacements from two points corresponding to two randomly produced number values between these two individuals [29]. Two point crossover is shown in Table 3.

Table 3. Two point crossover

Parent 1	1 0 1 0 1 1 1 0 ... 1 1 0 1 0 1 0 1 0 1
Parent 2	0 1 0 1 1 0 0 1 ... 0 1 1 0 0 1 0 1 1 1
Candidate Parent (Child 1)	**0 1 0 1 1 0 0** 0 ... 1 **1 1 0 0 1 0 1 1 1**
Candidate Parent (Child 2)	**1 0 1 0 1 1 1** 1 ... 0 **1 0 1 0 1 0 1 0 1**

3.3.3. Multi point crossover (MPX)

More than two random numbers are produced in this crossover operator. If these numbers are lower than the determined crossover rate, two individuals that was selected by tournament method will be selected. New individuals are produced by making replacements from points corresponding to randomly produced number values between these two individuals [29]. Multi point crossover is shown in Table 4.

Table 4. Multi point crossover

Parent 1	1 0 1 0 1..1 0 1 0 1..1 1 1 0..0 1 0 1
Parent 2	0 1 0 1 1..1 0 1 1 0..1 0 1 1..0 1 1 1
Candidate Parent (Child 1)	**0 1 0 1** 1..1 **0 1 1 0**..**1 0 1 1**..**0 1 1 1**
Candidate Parent (Child 2)	**1 0 1 0** 1..1 **0 1 0 1**..**1 1 1 0**..**0 1 0 1**

3.3.4. Order based crossover (OBX)

A group of points is selected randomly in this method. The characters corresponding to the points selected as the first chromosome exactly save their places. The characters belonging to the selected points of the second chromosome are placed behind the characters placed in the same points of the first chromosome. In the other empty positions, a new chromosome is created by placing the disused genes of the first chromosome (from left to right) respectively, also considering the genes transferred by the second chromosome [30].

3.3.5. Linear ordered crossover (LOX)

It was developed by Falkenauer and Bouffouix. Operation degrees [30] are given as follows:

1. Select two parents from the existing population randomly,
2. Select two inferior consecutions in the two selected chromosomes,
3. Detach the inferior consecution selected from P_1 consecution from the chromosome and determine the empty places, likewise carry out the same processes in the P_2 consecution,
4. Place the first inferior consecution into P_1 and the second into P_2.

3.3.6 Mutation

In many studies, the conclusion that mutation rate must be taken between %0.5 and %1.5 has been obtained, GA has been operated many times and mutation rate (P_m) has been determined as 0.005. Mutation process is shown in Table 5. Mutation formula [29,31] is given as follows:

$$\frac{1}{PN} < P_m < \frac{1}{l} \tag{11}$$

Tablo 5. Mutation

Candidate individual 1 before mutation
1 0 1 0 1..1 0 1..0 0..1..1 1..1 0 1
Candidate individual 1 after mutation
1 0 1 **1** 1..1 **1** 1..0 **1**..**0**..**0**..**0** 0 1

4. RESULTS

The proposed method has been applied to two test systems; a power system with 3 and 6 units system respectively. The cost function of each unit is chosen as a quadratic function for the test systems. The proposed method is compared with Lagrange function [23] and Tabu Search, NSGA-II [24]. The first test system has 3 units and details of this test system are given in Table 6. The system demand is 850 MW in all simulations.

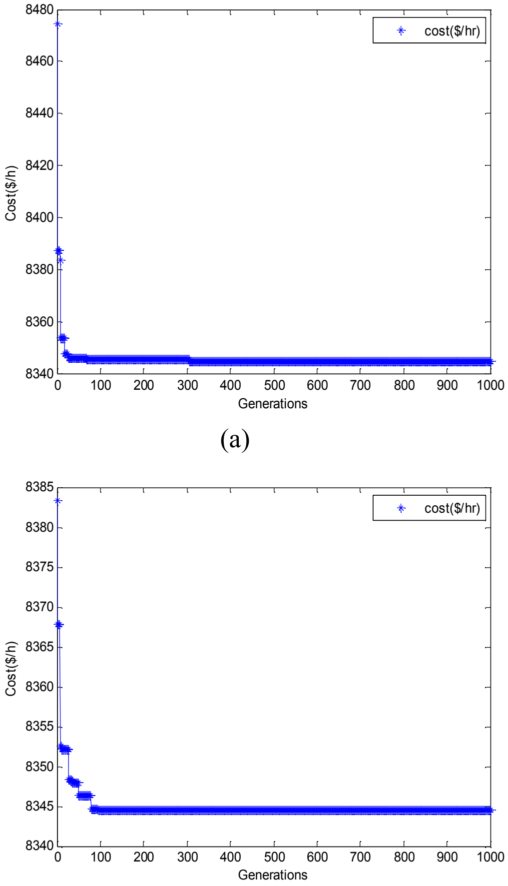
Table 6. Fuel cost coefficients

Unit (i)	a_i	b_i	c_i	$P_{G_i}^{\min}$ (MW)	$P_{G_i}^{\max}$ (MW)
1	561	7.92	0.001562	150	600
2	310	7.85	0.00194	100	400
3	78	7.97	0.00482	50	200

The system transmission losses are calculated using simplified loss expression:

$$P_L = 0.00003\, P_{G_1}^2 + 0.00009\, P_{G_2}^2 + 0.00012\, P_{G_3}^2 \tag{12}$$

The power system for the 3-unit system has been solved with line loss and without line loss by the proposed method. The minimum cost values of the system are given in Table 7 and Table 8 respectively, the cost curves are given in Figure 3.

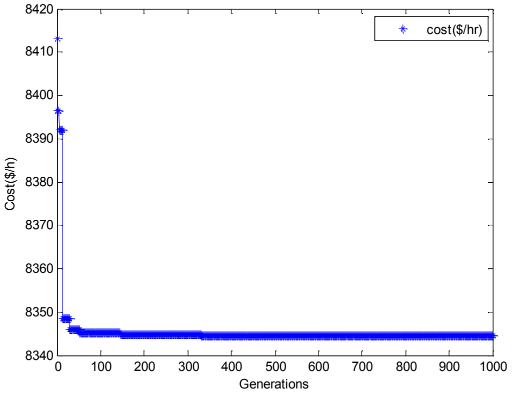


(a)

(b)

Table 7. 3-Unit System results in the status with line loss

850 MW for demand load					
Crossover methods of GA	P_{G_1} (MW)	P_{G_2} (MW)	P_{G_3} (MW)	Loss (MW)	Cost($/h)
OPX	430.9702	302.3469	132.5831	15.9002	8344.5823
OBX	438.9767	297.2381	129.5251	15.7399	8344.5919
TPX	439.4848	298.0071	128.2617	15.7536	8344.5991
MPX	435.4060	300.8637	129.5663	15.8360	8344.5455
LOX	435.2824	301.3031	129.2642	15.8497	8344.5144
Tabu Search [24]	435.69	298.828	131.28	15.798	8344.598
NSGA-II [24]	436.366	298.187	131.228	15.781	8344.606



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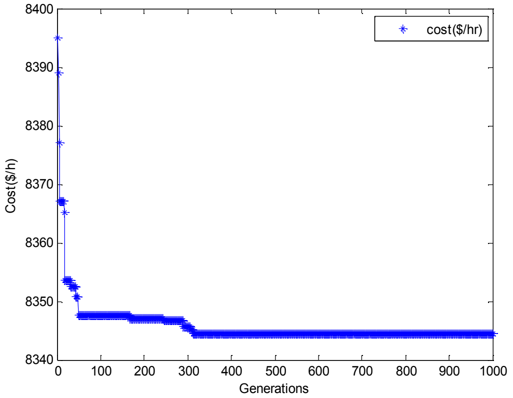

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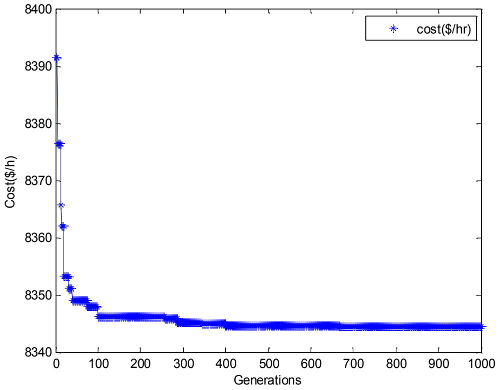

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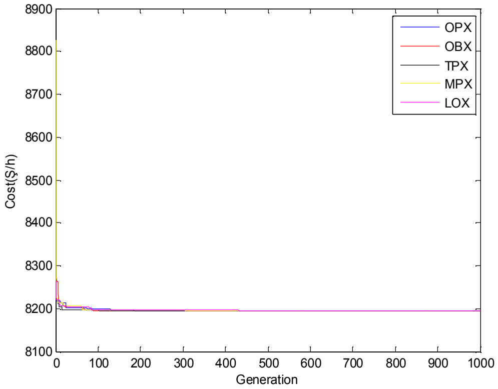
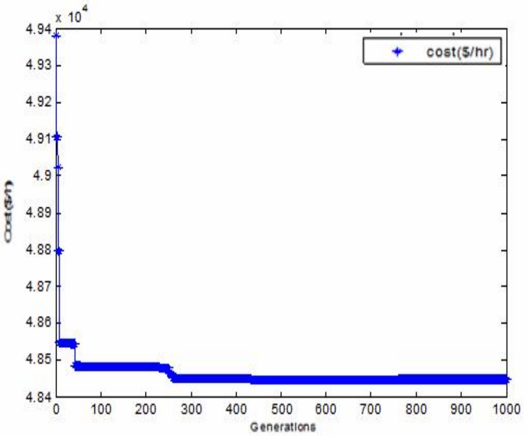


(f)

Figure 3. The curves of the results obtained by the proposed method in 3-unit system and in the status with line loss and without line loss: a) OPX b)OBX c) TPX d) MPX e) LOX f) All curves of the results in the status without line loss

Generator data of a 14 buses 380 KV 6 units [23] power system used in Turkey is given in Table 9, the results with line loss and without line loss obtained by the proposed method are given in Table 10 and Table 11 and the cost curves are given in Figure 4.



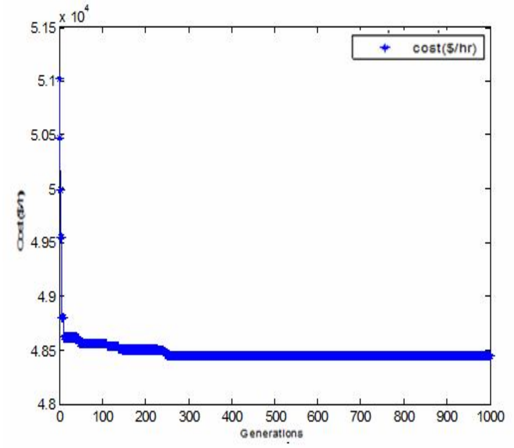
(a)

Table 8. 3-Units System results in the status without line loss.

850 MW for demand load				
Crossover methods of GA	P_{G_1} (MW)	P_{G_2} (MW)	P_{G_3} (MW)	Cost($/h)
OPX	403.4898	332.8440	113.6586	8194.8125
OBX	391.7066	332.8990	125.382	8194.3566
TPX	396.1974	327.7261	126.0689	8194.4636
MPX	378.4402	345.2956	126.2612	8194.9673
LOX	390.6491	338.4106	120.9326	8194.3324

Table 9. Fuel cost coefficients

Unit (i)	a_i	b_i	c_i	$P_{G_i}^{\min}$ (MW)	$P_{G_i}^{\max}$ (MW)
1	6780.5	5.682	0.0106	318	1432
2	1564.4	3.1288	0.0139	150	600
3	5134.1	6.2232	0.0168	210	990
4	1159.5	3.3128	0.021	110	420
5	1697	3.2324	0.0137	140	630
6	1822.8	3.472	0.0147	140	630



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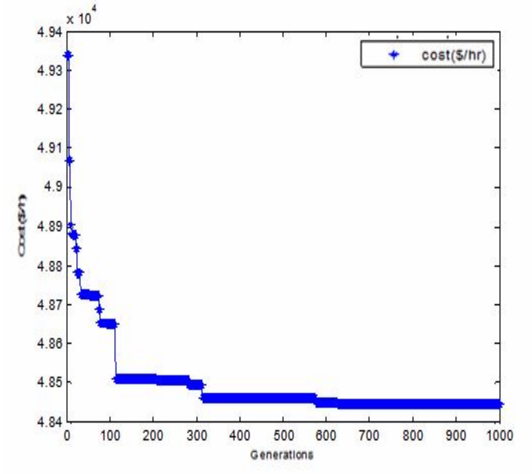

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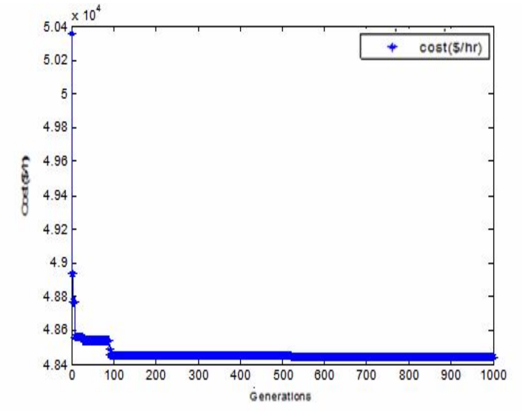

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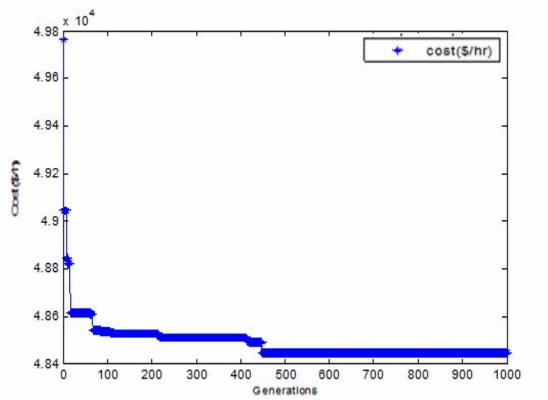

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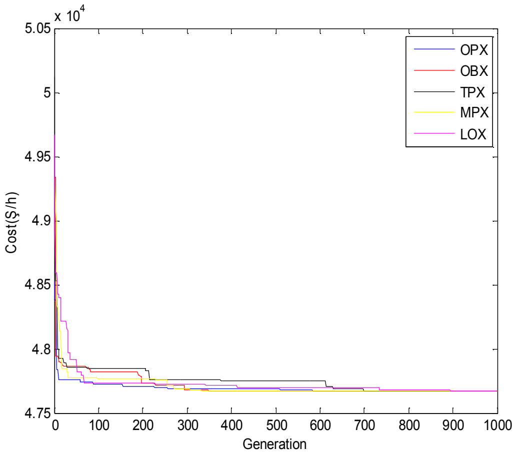

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Figure 4. The curves of the results obtained by the proposed method in 6-units system and in the status with line loss and without line loss: a) OPX b)OBX c) TPX d) MPX e) LOX f) All curves of the results in the status without line loss

Table 10. 6-Units System results in the status with line loss.

2734.9 MW for demand load								
Crossover methods of GA	P_{G_1} (MW)	P_{G_2} (MW)	P_{G_3} (MW)	P_{G_4} (MW)	P_{G_5} (MW)	P_{G_6} (MW)	Loss (MW)	Cost($/h)
OPX	577.9458	523.3543	356.1116	344.9385	511.7133	464.9071	44.1	48449.4102
OBX	552.8556	512.0518	348.5894	352.2517	530.4508	482.8071	44.1	48442.2275
TPX	566.1826	518.0120	336.9729	326.6793	538.8250	492.3478	44.1	48444.0358
MPX	557.2412	527.0623	355.1357	338.8174	510.3076	490.4038	44.1	48444.8812
LOX	571.3503	523.5191	322.1189	356.6793	521.8671	483.4501	44.1	48446.6477
LF[23]	573.0010	520.3039	352.5975	335.5975	523.9189	472.2131	44.125	48481

Table 11. 6-Units system results in the status without line loss

2734.9 MW for demand load							
Crossover methods of GA	P_{G_1} (MW)	P_{G_2} (MW)	P_{G_3} (MW)	P_{G_4} (MW)	P_{G_5} (MW)	P_{G_6} (MW)	Cost ($/h)
OPX	549.7618	530.0699	319.5718	346.2252	505.0737	484.1081	47673.9306
OBX	565.7407	526.5816	319.2862	322.8193	526.6225	473.8347	47672.3121
TPX	537.4546	516.5838	326.6417	351.1542	514.3602	488.6242	47672.7998
MPX	553.3315	497.0138	329.9268	340.6528	527.1908	486.6952	47669.3598
LOX	544.7301	529.9188	316.1678	345.2791	528.4021	470.1709	47675.1998

5. CONCULUSION

Due to the increased demand for power in both our country and the world, optimization studies in electrical power systems are carried out. The ED problem, one of the optimization problems in power systems, is becoming more important. Analyzing and planning the existing systems better is necessary in order to meet the increased power demand in the most appropriate way. This paper introduces an approach based on different crossover operators of GA to study the power system economic dispatch, which is formulated as a constrained optimization problem. The proposed method has been applied to two test system. Firstly in this study, the 3-unit power system has been regarded as with line loss and without line loss. The existing operation results of ED problem has been compared with the results of TS and NSGA-II by using different crossover operators of the genetic algorithm. Secondly, the results obtained by the proposed method have been compared with the existing study result LF by regarding the 6-unit system with line loss and without line loss. According to the simulation results, it has been seen that the minimum cost results, obtained by the proposed method in two different power systems, have given better results. An advantage of using the proposed method is that it gives better results than the solutions obtained by mathematical methods in the solution of ED problem, one of the optimization problems in power systems, and can contribute much to a country's economy by being used in planning and operating the power systems in accordance with the demanded power.

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