Solution to Environmental Economic Power Dispatch Problems in Hydrothermal Power Systems by Using Genetic Algorithm

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Abstract

In this study, the environmental economic power dispatch problem in hydrothermal power systems has been solved by using genetic algorithm. In the process of solution, the use of the demanded amount of water by each of the hydraulic units has been provided as well as the minimization of total thermal cost and total NO_x emission. In order to convert the environmental economic power dispatch problem, which is one of the multi-objective optimization problems, into a single objective optimization problem weighted sum method (WSM) has been used. Genetic algorithm (GA) method has been applied to single objective optimization problem for the solution. As an example, the solution of a lossy system with 16 buses consisting of thermal and hydraulic generation units has been given. Considering the one-day operation period of the sample system, solutions have been obtained for various values of weight factor w and the obtained total thermal cost and total NO_x emission values (pareto optimal results) have been evaluated.

Keywords : *Hydrothermal power systems, Environmental economic power dispatch, Weighted sum method, Genetic algorithm*

1. Introduction

The optimal operation and planning of power generation systems has a very significant place in power generation. Generally the optimal use of a power system means the minimization of the fuel that will be used. However, today the widespread use of fossil-based fuels in generation units makes it inevitable to consider the environmental pollution caused by the generation units in the solution of the problems. Therefore, in this study the solution of environmental economic power dispatch problem considering the environmental pollution as well as the minimization of the cost has been investigated. The optimal operation of systems with hydraulic units during a periodical term is more complicated than that of systems which contain only thermal units. Because, hydraulic units both electrically (like feeding the same loads) and hydraulically are dependent on each other. The solution of the problem gives active power generation values of generation units providing the potential thermal and hydraulic constraints which minimize the total cost during the projected operation period.

Several methods and algorithms have been developed so far for the solution of the environmental economic power dispatch problems. In literature, the solution of some environmental economic power dispatch problems has been shown as multiobjective optimization problem directly by multiobjective evolutionary algorithm in [1] and by multiobjective particle swarm optimization method in [2]. After the problem has been converted into single objective optimization problem by weighted sum method, it has been solved by using first order gradient method in [3], by genetic (or modified genetic) algorithm in [4-6], by the goal-attainment method and a partition approach algorithm in [7] and by analytical solution in [8].

In practice, majority of problems require simultaneous optimization of frequently encountered objectives which cannot be compared with each other. Generally, in such problems there is not only a single solution, but a set of alternative solutions may exists. When all the objectives for the elements of these solutions are considered, none of them can be said to be better than the others. Such solutions are called as *Pareto optimal solutions* [9].

In the solution of optimization problems, *GA* can reach general optimum without getting stuck on the local optimums. Therefore, in the solution of environmental economic power dispatch problem scalarized by weighted sum method belonging to hydrothermal power systems *GA*, method has been preferred.

2. Problem Formulation

The solution of environmental economic power dispatch problem in hydrothermal power system is found by the minimization of total cost function (total thermal cost and total NO_x emission amount) under all possible thermal and hydraulic constraints. The thermal cost of the generation units in the system has been taken for each unit as the second order function of the active power generation as follows [10,11].

$$F_n(P_{Gs,n}) = a_n + b_n.P_{Gs,n} + c_n.P_{Gs,n}^2 \quad (R/h)^{1} \qquad (1)$$

The amount of emission NO_x produced by each thermal unit, has been defined as the second degree function of the unit's output power type as in (2) [4].

$$E_n(P_{Gs,n}) = d_n + e_n.P_{Gs,n} + f_n.P_{Gs,n}^2 \quad (ton/h) \qquad (2)$$

The input-output curve of hydraulic units represents the change of the amount of water discharged per hour according to the active power that is produced. The amount of water discharged from hydraulic units per hour given in equation (3) has been taken as a two-parted curve [10,11].

$$q_m(P_{GH,m}) = \begin{cases} d_{1,m} + d_{2,m}.P_{GH,m} \\ \qquad , if \ P_{GH,m}^{\min} \le P_{GH,m} \le P_{GH,m}^{knee} \\ d_{3,m} + d_{4,m}.P_{GH,m} + d_{5,m}.P_{GH,m}^2 \\ \qquad , if \ P_{GH,m}^{knee} \le P_{GH,m} \le P_{GH,m}^{\max} \end{cases} \qquad (3)$$

[1] *R* stands for a fictitious monetary unit.

The unit of $P_{Gs,n}$ in equations (1), (2) and $P_{GH,m}$ in (3) is taken as *MW*. The power balance constraint in a lossy system has been shown in (4).

$$\sum_{n\in N_S} P_{Gs,nj} + \sum_{m\in N_H} P_{GH,mj} - P_{load,j} - P_{loss,j} = 0, \quad j = 1,....,j_{\max} \tag{4}$$

Thermal and hydraulic constraints of thermal and hydraulic units have been given below.

$$P_{Gs,n}^{\min} \le P_{Gs,nj} \le P_{Gs,n}^{\max}, \quad n\in N_S, \ j = 1,\ldots,j_{\max} \tag{5}$$

$$P_{GH,m}^{\min} \le P_{GH,mj} \le P_{GH,m}^{\max}, \quad m\in N_H, \ j = 1,....,j_{\max} \tag{6}$$

$$q_m^{\min} \le q_{mj}(P_{GH,mj}) \le q_m^{\max}, \quad m\in N_H, \ j = 1,....,j_{\max} \tag{7}$$

$$V_m^{\min} \le V_{mj} \le V_m^{\max}, \quad m\in N_H, \ j = 1,....,j_{\max} \tag{8}$$

$$V_{m0} = V_m^{init.}, \quad V_{mj_{\max}} = V_m^{end}, \quad m\in N_H \tag{9}$$

The inflow water rate into the m^{th} hydraulic unit's reservoir in the j^{th} subinterval is known as $r_{mj},(acre-ft/h)$. The total water amount discharged from this hydraulic unit has been given below.

$$\begin{aligned} q_{total,m} &= \sum_{j=1}^{j_{\max}} q_{mj}(P_{GH,mj}) t_j \\ q_{total,m} &= V_m^{init.} - V_m^{end} + \sum_{j=1}^{j_{\max}} r_{mj}.t_j \end{aligned} \quad , \ m\in N_H \tag{10}$$

In the calculation of the stored water amount of m^{th} hydraulic unit at the end of j^{th} subinterval is used the equation below.

$$V_{mj} = V_{mj-1} + \left[r_{mj} - q_m(P_{GH,mj}) \right].t_j \tag{11}$$

In the system m_1^{st} and m_2^{nd} units are tied to each other serially, if m_2^{nd} hydraulic unit is after m_1^{st} hydraulic unit, the water discharged from m_1^{st} hydraulic unit enters into the reservoir of m_1^{st} hydraulic unit. In this case, the water amount stored in the reservoir of m_2^{nd} hydraulic unit at the end of j^{th} subinterval is calculated according to (12).

$$V_{m_2,j} = V_{m_2,j-1} + \left[q_{m_1}(P_{GH,m_1 j}) - q_{m_2}(P_{GH,m_2 j}) \right].t_j \tag{12}$$

In this study it is assumed that there is no time delay between the water discharged from hydraulic unit m_1 and the water enters directly to reservoir of the hydraulic unit m_2. The total amount of water that will be spent by hydraulic unit m_2 is calculated according to q_{total,m_2} (13) [10,11].

$$q_{total,m_2} = q_{total,m_1} + V_{m_2}^{init.} - V_{m_2}^{end} \tag{13}$$

The explanation of the expressions used in the equations above is as follows.

Gs, GH = Active/reactive power generation indices for thermal and hydraulic units.

ref = Reference bus to which a normal thermal generation unit is connected.

n, m = Indices of the buses to which a thermal and a hydraulic unit is connected, respectively.

j, j_{max} = Subinterval index and number of subintervals, respectively.

t_j = Length of subinterval *j, (h)*.

$P_{Gs,nj}, P_{GH,mj}$ = Active generations of the n^{th} thermal and the m^{th} hydraulic units in the j^{th} subinterval, *(MW)*.

$P_{load,j}, P_{loss,j}$ = Total system active load and loss in the j^{th} subinterval, respectively, *(MW)*.

$P_{Gs,n}^{min}, P_{Gs,n}^{max}$ = Lower and upper active generation limits of the n^{th} thermal unit, respectively, *(MW)*.

$P_{GH,m}^{min}, P_{GH,m}^{max}$ = Lower and upper active generation limits of the m^{th} hydraulic unit, respectively, *(MW)*.

$q_{mj}(P_{GH,mj})$ = Water discharge rate of the m^{th} hydraulic unit in the j^{th} subinterval, *(acre-ft/h)*.

q_m^{min}, q_m^{max} = Lower and upper discharge rate limits for the m^{th} hydraulic unit, respectively, *(acre-ft/h)*.

$q_{total,m}$ = Total water amount to be used by the m^{th} hydraulic unit during the operation period, *(acre-ft)*[1].

V_{mj} = Stored water amount in the m^{th} hydraulic unit's reservoir at the end of the j^{th} subinterval, *(acre-ft)*.

V_m^{min}, V_m^{max} = Lower and upper reservoir storage limits of the m^{th} hydraulic unit, respectively, *(acre-ft)*.

V_m^{init}, V_m^{end} = Starting and final water amounts in the m^{th} hydraulic unit's reservoir, respectively, *(acre-ft)*.

r_{mj} = Inflow water rate into the m^{th} hydraulic unit's reservoir in the j^{th} subinterval, *(acre-ft/h)*.

N_S, N_H = Sets containing all thermal and hydraulic units in a given power system, respectively.

The total cost function *(TCF)* of environmental economic power dispatch problem scalarized by weighted sum method in the hydrothermal power system that is to be minimized has been given in equation (14).

$$TCF = \sum_{j=1}^{j_{\max}} t_j \sum_{n\in N_S} \left[wF_{nj}(P_{Gs,nj}) + (1-w)\gamma_n E_{nj}(P_{Gs,nj}) \right], R \tag{14}$$

In the equation γ_n represents NO_x emission cost at thermal unit *n* as *(R/ton),* and *w* represents the weight factor which changes as *(0≤w≤1)*. Here, *w=1.0* value corresponds only to the minimum thermal cost, and *w=0.0* value corresponds only to minimum NO_x emission amount. Once the active power generation values that minimize *TFC* in equation (14) by *GA* are found, the daily total thermal cost of the system *(TTC)* and daily total NO_x emission amount *(TER)* are calculated in equations (15) and (16), respectively.

$$TTC = \sum_{j=1}^{j_{\max}} t_j \sum_{n\in N_S} F_{nj}(P_{Gs,nj}), \quad (R) \tag{15}$$

$$TER = \sum_{j=1}^{j_{\max}} t_j \sum_{n\in N_S} E_{nj}(P_{Gs,nj}), \quad (ton) \tag{16}$$

3. Genetic Algorithm Method

GA is used in the solution of the problems which are difficult or impossible to solve by traditional methods. *GA* is actually derived from a simple model of society genetic. The

[1] $1\ acre-ft = 1233.5\,m^3$

algorithm firstly starts with a solution set that is termed as population and represented by chromosomes. The results taken from this population are used to form a new population which is expected to contain better solutions than the previous one. Since the compatible ones have the potential to produce better results, the solutions chosen to form new population are selected according to their compatibility. This process is carried on until a particular state is provided (for instance, the development of a definite number of societies or the development of best solution).

The process that the *GA* undergoes until it reaches the best solution can be defined as the formation of new individuals by codification of solution set, formation of initial population, calculation of the compatibility of solutions in population, selection of progenitor individuals according to their compatibility, crossover and mutation [4,12,13].

3.1. The Application of Genetic Algorithm to the Problem

In this study, to explain the application of *GA* to the problem, the generation units in the system have been shown by a general expression as $P_{G,g}$. If the generation unit is thermal unit then $P_{G,g} = P_{Gs,n}$. If, however, it is hydraulic unit then $P_{G,g} = P_{GH,m}$. The number of generation units in the system is $g \epsilon N_G$. N_G shows the set of all generation units. The total generation unit set of the system is the sum of sets of thermal and hydraulic units as is seen below.

$$N_S + N_H = N_G \qquad (17)$$

First of all, in order to show the *bn* bit number (solution sensitivity), numbers lacking one from the elements of random N_G set (reference bus) providing the constraint in (18), are assigned for the $P_{G,gj}$ values which are output powers of generation units.

$$0 \le P_{G,gj}^{init.} \le 2^{bn} - 1\,,\ \ g \in N_G\,,\ ref \ne g\,,\ j = 1,\ldots,j_{\max} \qquad (18)$$

Since these assigned numbers can take a value other than the present constraints of generation units in the system, they are made appropriate for the constraints by performing mapping according to equation (19).

$$P_{G,gj}^{new} = P_{G,g}^{\min} + \frac{P_{G,g}^{\max} - P_{G,g}^{\min}}{2^{bn} - 1} . P_{G,gj}^{init.},\ \ g \in N_G \quad , \quad ref \ne g \quad , \quad j = 1,\ldots,j_{\max} \qquad (19)$$

Thus, the inequality constraints given between (5) and (7) are provided automatically. In this case, the individuals providing the condition below are taken as solution.

$$CP_{load} P_{load,j} < \Big(\sum_{n \in N_S, n \ne ref} P_{Gs,nj} + \sum_{m \in N_H} P_{GH,mj} \Big) < P_{load,j} \qquad (20)$$

The formation of the individuals is shown in Figure 1. This process continues until the number of the individuals selected for the population is completed.

	$P_{G,2}$	$P_{G,3}$		$P_{G,Ng}$
Individual N :	10...11	11...01	………	10...10
	(bn) bit	(bn) bit		(bn) bit

Figure 1. Creation of the individual (Except for the ref. bus)

After the individual is formed, the generation value of the reference bus is calculated by load flow. The total cost of the formed individual, the amount of water spent for the hydraulic unit and the amount of water left in the reservoirs are calculated in the first period. This process continues until the predefined period number. When the number of the period is completed, total cost of the system *(TCF),* water spent by hydraulic units and the last values of the water in the reservoirs are calculated. The individual is added to the population and compatibility function *(f)* is found from equation (21). In the optimal solution of the problem, f function is required to be a maximum [14].

$$f = \frac{1}{fv} = \frac{1}{TCF + PF} \qquad (21)$$

In the equation fv shows the compatibility value, while *PF* demonstrates the sum of penalty function that is added to find a solution appropriate to the constraints. When the solution proposed by the individual violates the constraints of the problem, it is punished. This penalty is added to the compatibility function in order to convert the solutions which are incompatible with the constraints into compatible ones.

In the problem; the generation value of the reference bus, the amount of water stored in the reservoirs of hydraulic units, and the amount of water left in the reservoirs of the hydraulic units at the end of the last time period must be controlled. If these values which have been controlled exceed the limit values, they are punished. The sum of the penalty function used here has been given in (22) [12,13].

$$PF = PFP_{ref} + PFV_m + PFV^{end} \qquad (22)$$

Since reference bus is considered as a thermal unit, reference bus penalty value (PFP_{ref}) is calculated according to equation (23).

$$PFP_{ref} = \begin{cases} \sum\limits_{j \in \{P_{Gs,ref\,j} < P_{Gs,ref}^{\min}\}} CP_{ref}\left(P_{Gs,ref}^{\min} - P_{Gs,ref\,j}\right)^2 \\ \sum\limits_{j \in \{P_{Gs,ref\,j} > P_{Gs,ref}^{\max}\}} CP_{ref}\left(P_{Gs,ref\,j} - P_{Gs,ref}^{\max}\right)^2 \\ 0 \quad if \quad P_{Gs,ref}^{\min} \le P_{Gs,ref\,j} \le P_{Gs,ref\,j}^{\max} \end{cases} \qquad (23)$$

The penalty function PFV_m which belongs to the amount of water stored in the reservoirs of hydraulic units has been given in equation (24), and the penalty function PFV^{end} belonging to the amount of water that is remained in the reservoirs of hydraulic units at the end of the last time period has been given in equation (25).

$$PFV_m = \begin{cases} \sum\limits_{j=1}^{j_{\max}-1} \sum\limits_{m \in N_H} CV_m\left(V_m^{\min} - V_{mj}\right)^2 \quad if\ \{V_{mj} < V_{\mathrm{m}}^{\min}\} \\ \sum\limits_{j=1}^{j_{\max}-1} \sum\limits_{m \in N_H} CV_m\left(V_m^{\max} - V_{mj}\right)^2 \quad if\ \{V_{mj} > V_{\mathrm{m}}^{\max}\} \\ 0 \quad if \quad V_m^{\min} \le V_{mj} \le V_m^{\max} \\ m \in N_H,\ j = 1,\ldots,j_{\max} - 1 \end{cases} \qquad (24)$$

$$PFV^{end} = \Big\{ \sum_{m \in N_H} CV^{end}\left(V_{mj_{\max}} - V_m^{end}\right)^2,\ j = j_{\max} \qquad (25)$$

The expressions of CP_{load}, CP_{ref}, CV_m and CV^{end} are coefficients which belong to penalty functions and they are values changing between *0* and *1*. These coefficients are defined by the users according to the applied system. The fv compatibility values found by the addition of penalties are listed from the small to the big *(1,2,3,............,ps)*. According to the order of the compatibility value all individuals are graded by using equation (26). This grading is done to define the field of each individual in the roulette wheel which will be formed. Since the individual with high grade (more appropriate one) will have more area in the roulette wheel than the other individuals, the chance of its selection will be higher.

$$score(TCF)_k = 5 + round\left[95.\left(\frac{ps-k+1}{ps}\right)^2\right] \quad (26)$$

In the equation *(k)* shows the place of the individual in the ordering, while *(ps)* demonstrates the number of the individual in the population. This grading is used in the selection of individuals which will be defined for the populations that are to be formed in the following iterations. In this way, the individual with higher grade will have more chance of being selected. The grading system in the equation has been used for a more successful selection process [4].

For the formation of the new population, the operations of elitism, selection, crossover and mutation are performed respectively. Firstly, the individual which has the highest grade (namely elite) in the present population is transferred to the following population without undergoing any operation. For the formation of the rest of the individuals, two individuals are selected. These two selected individuals are crossed by looking at the crossover rate. The individual that has been formed after the crossover is mutated depending on the rate. The cost, emission and water conditions are calculated by load flow with the new individual that was formed at the end of the operations of selection, crossover and mutation. According to these calculated values, new penalties are calculated and added to the object function. This process continues until the predefined period number and the number of individual in the population are completed. After the formation of the population, by calculating the total cost of individuals, the water spent by hydraulic units and the amount of water remained in the reservoirs the best solution is searched. By repeating these operations, the solutions in the populations that will be formed in different iterations are targeted to be better. When the targeted criterion is satisfied, the algorithm is ended by defining the best solution. The flow chart that is followed for the solution of the problem has been shown in Fig. 2.

In this study, the roulette wheel method for the selection, single pointed crossover as the type of crossover, single bit change as the mutation type, and iteration number as the stopping criterion have been used.

4. Example

As an example the sample power system in [10] which consists of sixteen buses, five normal thermal generation units, and four hydraulic generation units, has been studied. The voltage of the bus *1* (the reference bus) has been taken as $1.05\angle 0^0\, pu$. The base values in the system have been taken as $S_{base} = 100\ MVA$ and $U_{base} = 230\ kV$. In the solution of the system, a one-day (short term) operation period which contains six equal subintervals ($t_j = 4h, j = 1,...,6$) has been considered. Due to page limitations detailed explanation of the example solution can not be given here. It is going to be given during the presentation.

The penalty coefficients used in the solution of the problem have been taken as CP_{load}*=0.7*, CP_{ref}*=0.7*, CV_m*=0.6* and CV^{end}*=0.6*. As the genetic algorithm parameters iteration number *150*, solution sensitivity (bit number) *16*, population size (number of individual) *150*, elite chromosome number *1*, crossover rate *0.990*, and mutation rate have been chosen as *0.003*.

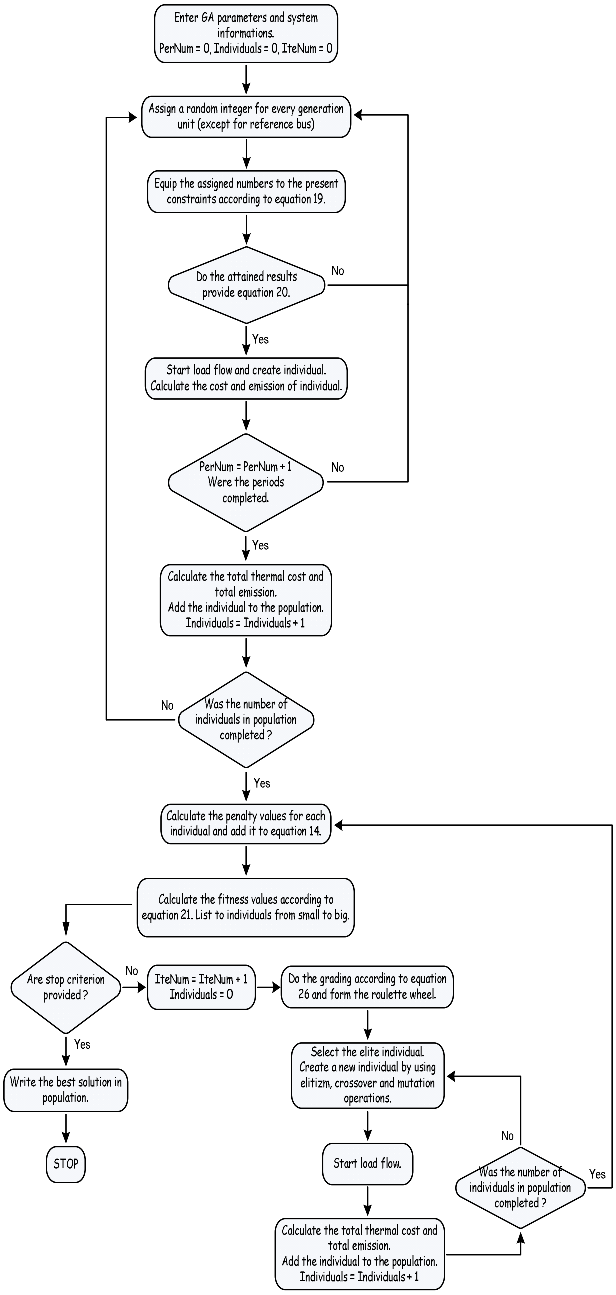

Figure 2. Flow chart of the algorithm

In the solution of the sample system with *16* buses, when the weight factor is taken as *w=1.0*, only thermal cost minimization can be done and total thermal cost of the system is *148767.66 (R)* and total NO_x emission amount is *7.78 (ton)*. When the weight factor is taken as *w=0.0*, only total NO_x emission amount minimization can be done and the total thermal cost of the system is *149616.81 (R)* and total NO_x emission amount has been calculated as *6.63 (ton)*. In both cases the water amount in the reservoirs of the hydraulic units has been left in the determined tolerance interval. When *w* starting from *0.0* is increased towards *1.0* with steps of *0.1*, change of total thermal cost and total NO_x emission rate have been shown in Fig. 3.

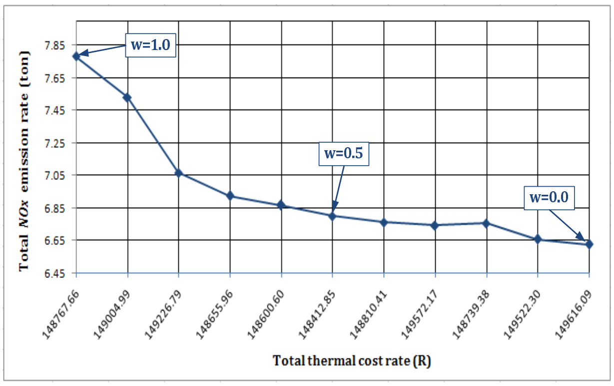

Figure 3. The effect of w value by using the WSM on the total thermal cost and the total NO_x emission rate.

In the solution of the problem based on the algorithm shown in Fig. 2 a visual simulation program has been developed and compiled by using Delphi programming language. Program has been run on a computer which has AMD 64X2 dual core processor and 2 GB of RAM.

5. Conclusion

Environmental economic power dispatch problem in hydrothermal power system has been scalarized by weighted sum method and has been minimized by *GA* method. The algorithm has been run *11* times with different weight factor starting from $w=1.0$ and being decreased with intervals of *0.1* until *0.0*. In the solutions providing, a maximum of *0.5%* tolerance values for hydraulic constraints, the total NO_x emission amount for the decreasing values of w has been seen to decrease while the total thermal cost has increased. At which point the sample power system will work is a decision that has been left to the decision-makers (owners of the system). In the solution of each value of w, under thermal and hydraulic constraints fitness value has been seen to converge to the optimal result beginning from about 10^{th} iteration.

6. References

[1] Abido M. A., November 2003, “Environmental/economic power dispatch using multiobjective evolutionary algorithms”, IEEE Transactions on Power Systems, Volume 18, No 4, p.1529-1537

[2] Abido M.A., 2009, "Multiobjective Particle Swarm Optimization for Environmental Economic Dispatch Problem", Electrical Power Systems Research, Vol. 79, pp:1105-1113.

[3] Yaşar C., Fadıl S., 2007, “Solution to environmental economic dispatch problem by using first order gradient method”, 5th International Conference on Electrical and Electronics Engineering, ELECO’2007, 5-9 December, Electric Control Proceeding, pp. 91-95, Bursa, TURKEY.

[4] Yaşar C., Özyön S. ve Temurtaş H., 2008, Termik üretim birimlerinden oluşan çevresel-ekonomik güç dağıtım probleminin genetik algoritma yöntemiyle çözümü, ELECO’2008, 5. Elektrik - Elektronik Mühendisliği Sempozyumu ve Fuarı, Elektrik-Kontrol Kitapçığı, s. 105-109, 26-30 Kasım 2008, BURSA.

[5] Chiang C. L., 2007, Optimal economic emission dispatch of hydrothermal power systems, Electrical Power and Energy Systems, Volume 29, p.462.469.

[6] Yalçınöz T., Köksoy O., 2007, "A Multiobjective Optimization Method to Environmental Economic Dispatch", Electrical Power and Energy Systems, Vol. 29, pp:42-50.

[7] Basu M., 2005, "A Simulated Annealing-Based Goal Attainment Method for Economic Emission Load Dispatch of Fixed Head Hydrothermal Power Systems", Electrical Power and Energy Systems, Vol. 27, pp:147-153.

[8] Palanichamy C., Babu N.S., 2008, "Analytical Solution for Combined Economic and Emissions Dispatch", Electrical Power Systems Research, Vol. 78, pp:1129-1137.

[9] Zitzler E., Thiele L., "Multiobjective Optimization Using Evolutionary Algorithms- A Comparative Case Study", Parallel Problem Solving From Nature-PPSN V, Amsterdam, The Netherlands, Springer-Verlag, September 1998, s. 292-301.

[10] Fadıl S., Yaşar C., 2001, A pseudo spot price algorithm applied to short term hydrothermal scheduling problem, Electric Power Components and Systems , Volume 29, No 11, p.112-119.

[11] Wood A. J., and Wollenberg B. F., (1996) “Power Generation Operation & Control”, John Wiley & Sons, 565 p.

[12] Fadıl. S., Ergün U.,1999, “Solution to Lossy Short Term Hydrothermal Coordination Problem with Limited Energy Supply Units By using Genetic Algorithm”, International Conference on Electrical and Electronics Engineering, ELECO’99, 1-5 December, Electrical Proceeding, pp. 234-238, Bursa, TURKEY.

[13] Goldberg D. E., 1989, “Genetic Algorithms in Search, Optimization, and Machine Learning”, Addison-Wesley Publishing Company, Inc., 412 p.

[14] Ergül, U., 2003, “Güç sistemlerinin optimizasyonunda genetik algoritmaların kullanımı”, Yüksek Lisans Tezi, Karadeniz Teknik Üniversitesi, 79 s. (yayımlanmamış).