Economic Environmental Optimization Using Harmony Search Method

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Abstract:- *The increase of the total electrical energy consumption has caused many deficiencies at the environment. The used numerical methods to solve this issue have proved inefficient due to convergence to a local optimum. The Harmony Search (HS) is a meta-heuristic method that mimics a jazz improvisation process by musicians in order to seek a fantastic state of harmony. In this paper, we have optimized the fuel cost and the greenhouse gases emission quantity using Harmony Search (HS) method and the obtained results are very interesting.*

Key words: *Economic fuel cost dispatch; environmental dispatch, economic environmental dispatch; Harmony search (HS)*

1. Introduction

The complicated constraints of the engineering optimization problems present a real challenge for researchers to find efficient and practical methods to solve it. These problems can be formulated, modeled and thus solved as nonlinear programming models. The methods for solving this kind of problems include traditional mathematical programming (such as linear programming, quadratic programming, dynamic programming, gradient methods and Lagrangian relaxation approaches [1]) and modern meta-heuristic methods (such as simulated annealing, genetic algorithms, evolutionary algorithms, adaptive Tabu search, particle swarm optimization, etc. [2]). Some of these methods are successful in locating the optimal solution, but they are usually slow in convergence and require very expensive computational cost. Some other methods may risk being trapped to a local optimum, which is the problem of premature convergence.

Economic load dispatch is one of well-known problems in a field of power system optimization [3]. The problem of dividing the total load demand among available online generators economically and also satisfying various system constraints simultaneously is called economic load dispatch. This is an important task in power system for allocating power generations among the committed units such that the constraints imposed are satisfied, the energy demands are met, and the corresponding cost is minimized. Improvements in scheduling of the unit generations can lead to significant cost savings. In view of the nonlinear characteristics of this problem, there is a demand for the optimization methods that do not have restrictions on the shape of the fuel-cost curves [4]. In addition, the increasing public awareness of the environmental protection and the passage clean air act amendments have forced utilities to reduce pollution and atmospheric emission of thermal power plants[5]. Several strategies to reduce the atmospheric emissions have been proposed these strategies require installation of new equipment they can be considered as long-term options and involve considerable capital outlay. The emission dispatch option is an attractive short-term alternative in which the emission in addition to the fuel cost objective is to be minimized. Thus the ED problem can be handled as a multi-objective optimization problem with non-commensurable and contradictory objective [6]. Different techniques have been reported in the literature pertaining to combined environmental economic dispatch (EED) problem. The EED problem has been reduced to a single objective problem by introducing price penalty factor.

This paper solves an economic load dispatch problem using the harmony search method. The test considers a six-unit generating system acquired from the standard IEEE 30-bus test system [7]. The proposed method proves to be a robust optimization technique for solving economic load dispatch problems.

2. Problem formulation

The main objective function presented in this paper is composed by three functions. The first and the second concern respectively the economic fuel and environmental dispatch problems, the last one deal with the economic environmental dispatch (EED) problem.

2.1 Economic fuel dispatch

The economic dispatch problem is to find the optimal combination of power generation in such a way that the total production cost of the entire system is minimized while satisfying the total power demand and some key power system constraints. The fuel cost for each power generation unit is defined. Hence, the total production cost function of economic dispatch problem is defined as the total sum of the fuel costs of all generating plant units as described follows.

$$F_T(P_g) = \sum_{i=1}^{N_G} \{a_i P_{gi}^2 + b_i P_{gi} + c_i\} \ \$/hr \qquad (1)$$

Where

N_G: Is the total number of generating units
F_T: Is the total production cost
P_{gi}: Is the power output of generating unit i
P_{gi}^{min}: Is the minimum output of generating unit i
a_i, b_i, c_i: Are fuel cost coefficients of unit i

2.2 Environmental dispatch

The Environmental Dispatch problem is to minimize the emission objective function, while satisfying several equality and inequality constraints. Generally the problem is formulated as follows. The total emission $E(P_g)$ of atmospheric pollutants caused by fossils-fuelled thermal units can be expressed as [8], [9]:

$$E(P_g) = \sum_{i=1}^{N_G} \{\alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i\} \ kg/hr \qquad (2)$$

Where:
$\alpha_i, \beta_i, \gamma_i$: are coefficients of the generator emission characteristics.

2.3 Economic environmental dispatch

The study of environmental economic dispatch involves the simultaneous minimization of two functions given by (1) and (2). One possible solution is to convert the bi-objective Economic Environmental Dispatch problem into a single-objective optimization problem, by introducing the price penalty factor; this factor is defined as the ratio between the maximum cost and maximum emissions of each generator [10]:

$$F_{pi} = \frac{F(P_{gi}^{max})}{E(P_{gi}^{max})}, i = 1, \dots, n_g \qquad (3)$$

The following steps are used to find the price penalty factor for a particular load demand

1) Find the ratio between maximum fuel cost and maximum emission of each generator.
2) Arrange the values of price penalty factor in ascending order.
3) Add the maximum capacity of each unit P_{gi}^{max} one at a time, starting from the smallest F_{pi} unit until $\sum P_{gi}^{max} \geq P_D$
4) At this stage, F_{pi} associated with the last unit in the process is the price penalty factor F_p for the given load.

The economic-environmental dispatch can be representing by following equation [11]:

$$\psi(P_g) = \sum_{i=1}^{N_G} (a_i P_{gi}^2 + b_i P_{gi} + c_i) + F_p \sum_{i=1}^{N_G} \alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i \qquad (4)$$

Eq. (4) can be rewritten in the following way:

$$\psi(P_g) = \sum_{i=1}^{N_G} \{A_i P_{gi}^2 + B_i P_{gi} + C_i\} \ \$/ton \qquad (5)$$

With:
$A_i = a_i + F_p \alpha_i$

$B_i = b_i + F_p \beta_i$

$C_i = c_i + F_p \gamma_i$

2.4 Problem constraints

There are equality and inequality constraints in this kind of problems. A power balance equation (6) is set as an equality constraint whereas the limits of power generation output (7) are inequality constraints.

$$\sum_{i=1}^{N_G} P_{gi} = P_D \qquad (6)$$

$$P_i^{min} \le P_i \le P_i^{max}, i = 1,2, \dots, N_G \qquad (7)$$

Where:
P_D: Is the total power demand of the plant
P_i^{min}: Is the minimum output of generating unit i
P_i^{max}: Is the maximum output of generating unit i

3. Harmony search (HS)

The harmony search algorithm [12] was conceptualized from the musical process of searching for a 'perfect state' of harmony, such as jazz improvisation. Jazz improvisation seeks a best state (fantastic harmony) determined by aesthetic estimation, just as the optimization algorithm seeks a best state (global optimum) determined by evaluating the objective function. Aesthetic estimation is performed by the set of pitches played by each instrument, just as the objective function evaluation is performed by the set of values assigned by each decision variable. The harmony quality is enhanced practice after practice, just as the solution quality is enhanced iteration by iteration. Consider a jazz trio composed of a saxophone, double bass, and guitar. Assume there exists a certain number of preferable pitches in each musician's memory: saxophonist {Do, Mi, Sol}, double bassist {Ti, Sol, Re}, and guitarist {La, Fa, Do}. If the saxophonist plays note Sol, the double bassist plays Ti, and the guitarist plays Do, together their notes make a new harmony (Sol, Ti, Do) which is musically the chord C7. If this new harmony is better than the existing worst harmony in their memories the new harmony is included in their memories and the worst harmony is excluded from their memories. This procedure is repeated until a fantastic harmony is found.

However, its first version was invented as a combinatorial optimization where decision variables are discrete. To apply the harmony search method to the real world engineering in which many search spaces are continuous, some procedure of the harmony search method must be modified to be able to handle continuous search variables.

In order to use harmony search algorithm, unconstraint objective functions has been derived by Lagrange method. The unconstraint cost, emission and cost emission objective functions equations is shown below:

$$F_T(P_g) = \sum_{i=1}^{N_G} \{a_i P_{gi}^2 + b_i P_{gi} + c_i\} - K_1 \times \sum_{i=1}^{N_G} P_{gi} - P_D$$

$$E(P_g) = \sum_{i=1}^{N_G} \{\alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i\} - K_2 \times \sum_{i=1}^{N_G} P_{gi} - P_D$$

$$\psi(P_g) = \sum_{i=1}^{N_G} \{A_i P_{gi}^2 + B_i P_{gi} + C_i\} - K_3 \times \sum_{i=1}^{N_G} P_{gi} - P_D$$

Where K_1, K_2, K_3: Lagrange multiplier

4. Simulation

To verify the effectiveness of the proposed harmony search method, a six-unit thermal power generating plant acquired from the standard IEEE 30-bus test system was tested. Generator characteristic, that is generation limits, cost and emission coefficients, are taken from [14].The fuel cost and the emission coefficients for the six generators are shown in table in table 1 and 2.

TABLE 1
Fuel Cost Coefficients

Gen. i	$F_T = \sum_{i=1}^{N_G} \{a_i P_{gi}^2 + b_i P_{gi} + c_i\}$		
	a_i	b_i	c_i
1	0.00375	2.0	0
2	0.00175	1.5	0
3	0.06250	1.8	0
4	0.00834	2.0	0
5	0.02500	1.5	0
6	0.02500	1.8	0

TABLE 2
Emission Coefficients

Gen. i	$E(P_g) = \sum_{i=1}^{N_G} \alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i$		
	α_i	β_i	γ_i
1	6.490×10^{-6}	-5.554×10^{-4}	4.091×10^{-2}
2	5.638×10^{-6}	-6.047×10^{-4}	2.543×10^{-2}
3	4.586×10^{-6}	-5.094×10^{-4}	4.258×10^{-2}
4	3.380×10^{-6}	-3.550×10^{-4}	5.326×10^{-2}
5	4.586×10^{-6}	-5.094×10^{-4}	4.258×10^{-2}
6	5.151×10^{-6}	-5.555×10^{-4}	6.131×10^{-2}

The simulations were performed using MATLAB software. The tests were carried out by solving economic fuel cost, environmental and economic environmental dispatch of a single power demand case, $P_D = 283.4$ MW and the price penalty factor, $P_F = 1766.64$ ($/ton). For comparison purposes, The Sequential Quadratic Programming (SQP) method was also applied to solve this test case. The results of which are presented as follows.

4.1 Sequential quadratic programming (SQP) results:

TABLE 3
COST OBJECTIVE FUNCTION

P1	P2	P3	P4	P5	P6
107.23	80	15	35	26.085	20.085

Cost Objective function value: 612.4339 $\$/hr$

TABLE 4
EMISSION OBJECTIVE FUNCTION

P1	P2	P3	P4	P5	P6
57.657	70.743	50	35	30	40

Emission Objective function value: 0.1936 kg/hr

TABLE 5
COST EMISSION OBJECTIVE FUNCTION

P1	P2	P3	P4	P5	P6
57.646	70.754	50	35	30	40

Cost Emission Objective function value: 342.7668 $\$/ton$

4.2 HS results:

Harmony search parameters :

Length of solution vector	60
HM Accepting Rate	0.95
Pitch Adjusting rate	0.7

TABLE 6
COST OBJECTIVE FUNCTION

P1	P2	P3	P4	P5	P6
38.153	11.288	15.745	34.675	34.120	31.820

Cost Objective function value: 385.0107 $\$/hr$

TABLE 7
EMISSION OBJECTIVE FUNCTION

P1	P2	P3	P4	P5	P6
39.269	48.565	49.364	44.362	50.245	49.403

Emission Objective function value: 0.1862 kg/hr

TABLE 8
COST EMISSION OBJECTIVE FUNCTION

P1	P2	P3	P4	P5	P6
42.336	52.514	55.136	51.366	55.208	52.713

Cost Emission Objective function value: 328.39 $\$/ton$ (Total Cost)

The obtained results with HS method from table 6 to 8 are better than the SQP results from 3 to 5. The cost emission objective function value obtained by HS is less than the SQP by 4 %.

5. Conclusion

Solution methods of economic fuel cost, environmental and economic environmental dispatch problems are described in this paper. An efficient meta-heuristic search method (harmony search) are briefed and summarized. The results showed that a set of optimal dispatch solutions with respect to the economic objective can be efficiently found. As a result, the harmony search have demonstrated an ability to provide, accurate and feasible solutions for economic fuel cost, environmental and economic environmental dispatch problems within reasonable computation time enough to be compatible with on-line application.

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