ECONOMIC PRODUCTION WITH CONTROL POLLUTION IN THERMAL PLANTS USING SIMULATED ANNEALING OPTIMIZATION

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Abstract: *The generation of electric energy from the thermal plants needs the combustible fuel to move the turbines. These power plants exist for more than 100 years. As a result, the combustible fuel emites some gas like NO_x, SO_2, and CO_2 to the atmosphere. These gas emissions make an impact on environment (air pollution and water pollution). This paper presents a simulated annealing optimization for finding economic production with control pollution in the thermal plants. The paper formulates a multi objective dispatch problem with valve point effect considered in both fuel cost and emission functions. The multi-objective problem of the generation and emission dispatch is solved to find the generation levels that best compromise the generation cost and the emission level while satisfying the power balance constraint. The simulated annealing algorithm from is tested on a 10 generator test system with valve point effect. The results of the proposed method are compared with other techniques reported in recent literature.*

Key words: *thermal plant; economic dispatch; pollution; valve effect; multi-objective optimization.*

1. Introduction

The technical-economic characteristics of power plants are determining for their exploitation. Three types of characteristics have an influence for the exploitation of one short-term power plant: its production cost; its technical constraints and its reliability. The most important of these three characteristics is the variable cost of production. For thermal power plants, it reflects mainly the cost of the used fuel and the other costs of exploitation and maintenance of the power plant. The cost of the fuel is estimated by using values of specific consumption of heat (a quantity of necessary heat energy to produce some electricity) of the power plant and the price of the fuel [1].

The economic dispatching is a problem of static optimization which consists in distributing the production of the active power of the various power plants of the network, so as to exploit the latter in a most economical possible way. This distribution obviously has to respect the production limits of power plants. The variable to be optimized is thus the production cost [2].

On the other hand, the amendments of the world law of 1990 (clean Air Act Amendments) forced the producers of energy and the engineers in charge of the electrical energy management to modify their algorithms of standard optimization by taking in consideration the pollution (to reduce the emissions to the atmosphere of greenhouse gas by the thermal power plants which are toxic gases (NO_x, SO_2, and CO_2) [3] [4].

2. Thermal plants impact on environment

On the site of a thermal power plant, the emission of dusts and harmful gases pollute directly the air. Secondly, these dusts and most of the toxic gases are rejected in the atmosphere fall again on the ground with atmospheric precipitation (rain, snow) or in the form of dry particles, what causes the water and grounds pollution and at damage the flora and fauna [5].

In fact, the thermal power plant needs water for condensation purposes. This water, when heated, is generally rejected to short distance from the source point. If the plant produce electric power and heat (high-efficiency power plant), the amount of water released is lower. Depending on local conditions, the calories discharged may cause a thermal pollution of surface waters; as a result it increases the water temperature [5].

Fig. 1. Gas emission from thermal plant [6].

In early 1970s, an important increase of concentration of some greenhouse gases, in evident link with the anthropological activity, lead to predict the eventuality of a climate change by due to greenhouse effect. So that, the average temperature of the globe would become established near 18° C instead of 15° C [7].

3. Mechanism of thermal plants

The steam power plants exist for more than 100 years. The main improvement is the replacement in the Watt machines of piston motors by turbines. The maximum temperature of the steam, even under high pressure does not exceed 500° C, so that the steel blades of turbines resist well and can be thinned and profiled [8].

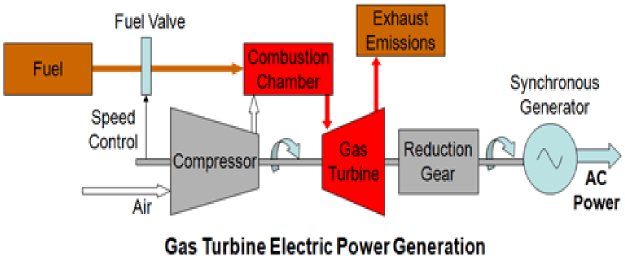

Fig. 2. Gas turbine electric power generation in thermal plant [10].

The thermal power plants have several valves of steam admission, which are used for the generated power control. Every time, a valve of admission is opened, we register a sudden increase of losses and it results undulations in the curve of fuel cost. With a gradual opening of valves, these losses decrease gradually until the valve is completely opened [9].

4. Economic and emission dispatch Problem formulation With Valve Effect

The valve-point effects are taken into consideration in the economic dispatch problem (ED) by superimposing the basic quadratic fuel-cost and characteristics with the rectified sinusoidal component as follows [10]:

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \times \sin\left(f_i \times \left(P_{i,\min} - P_i \right) \right) \right| \quad (1)$$

where a_i, b_i, c_i, e_i and f_i are the cost co-efficient of unit i.

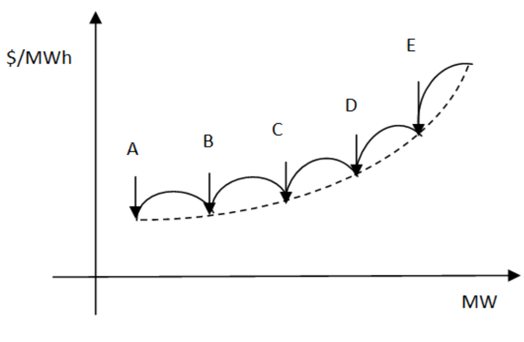

Fig. 3. Valve-point effect.

The valve-point effects are taken into consideration in the economic and emission dispatch problem (EED) by superimposing the basic quadratic gas emission and characteristics with the rectified exponential component as follow [11]:

$$E_i(P_i) = \alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i \times \exp(\delta_i \times P_i) \quad (2)$$

where α_i, β_i and γ_i are the emission co-efficient of unit i.

The transmission losses P_L can be found using B-coefficients

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij} P_i P_i \quad (3)$$

where B_{ij} is the transmission line coefficients.

The total supply must be equal to power demand

$$\sum P_i = P_D + P_L \quad (4)$$

where P_D is the load demand.

The above mentioned multi- objective optimization problem can be converted to a single objective optimization problem by introducing price penalty factors as follows:

$$F_{Ti}(P_i) = w_1 F_i(P_i) + w_2 E_i(P_i) \quad (5)$$

where w_1 and w_2 is weight factors of the multi-objective optimization of the economic and emission dispatch.

5. Simulated Annealing for economic and emission dispatch problem

Simulated Annealing is heuristic method which introduced in the field of optimization in 1980 by Kirkpatrick and independently by Cerny [12]. Simulated annealing is a robust, general-purpose combinatorial optimization algorithm based on probabilistic methods which has been applied to give the optimal solution for many areas such as VLSI circuit design, neural-networks, image processing, code design, capacitor placement in power systems, and economic load dispatch.

The name simulated annealing comes from an analogy between combinatorial optimization and the physical process of annealing. In physical annealing a solid is cooled very slowly, starting from a high temperature, in order to achieve a state of minimum internal energy. It is cooled slowly so that thermal equilibrium is achieved at each temperature. Thermal equilibrium can be characterized by the Boltzmann distribution

$$P_T\{X = x\} = (e^{-E_X/k_B T}) / (\sum_i e^{-E_i/k_B T}) \quad (6)$$

where X is a random variable indicating the current state, E_X is the energy of state x, k_B is Boltzmann's constant, and T is temperature.

The evolution of the state of a solid in a heat bath toward thermal equilibrium can be efficiently simulated by a simple algorithm based on Monte Carlo techniques which was proposed by Metropolis [13] in 1953.

Initialisation
Choose an initial solution $S \in X$;
*S** ← *S*;
C ← *0*; (Global iteration count)
T ← T_0; (T_0 Initial system temperature)
Iterative Processes
Nbiter ← 0 ;
While (Nbiter < nb_iter)
C ← *C+1*; Nbiter ← Nbiter+1;
Generate randomly a solution $S' \in N(S)$;
ΔF ← F(S)-F(S);
if *(ΔF <0)* **then**
S←S';
Otherwise
Prob (ΔF, T) ← exp (-ΔF/T);
Generate q uniformly in the interval: [0,1];
If (q< prob (ΔF, T)) **then**
S ← S';
If F(S) < F(S*) **then**
*S** ← *S*;
T= α T; (0 < α <1 cooling coefficient)

Fig. 4. Simulated Annealing Algorithm.

6. Simulations And Results

The proposed Simulated Annealing algorithm has been tested in a 10 generator system with valve effects. The software was implemented by the MATLAB language.

The generator cost coefficients, emission coefficients, generation limits, and loss coefficients of 10 units system are taken from [11]. The multi-objective EELD solution for the 10- unit system is solved using SA when system demand is 2000 MW.

For conducting the test, the initial temperature is fixed at 20 C°, alpha is fixed at 0.99 and max tries is 10000. The final temperature is 1e-10 C°.

Table 1 and table 2 present the economic solution and the environmental solution respectively.

Table 1
Best fuel cost.

	ABC_PSO [11]	DE [14]	SA
P_1	55	55	54.9999
P_2	80	79.89	80
P_3	106.93	106.8253	107.6263
P_4	100.5668	102.8307	102.5948
P_5	81.49	82.2418	80.7015
P_6	83.011	80.4352	81.1210
P_7	300	300	300
P_8	340	340	340
P_9	470	470	470
P_{10}	470	469.8975	470
Losses (MW)	87.0344	/	87.0434
F ($/hr)	111500	111500	111498.6581
E(lb/hr)	4571.2	4581	4584.8366

Table 2
Best gas emission.

	ABC_PSO [11]	DE [14]	SA
P_1	55	55	54.9999
P_2	80	80	80
P_3	81.9604	80.5924	76.6331
P_4	78.8216	81.0233	79.4332
P_5	160	160	160
P_6	240	240	240
P_7	300	292.7434	287.9285
P_8	292.78	299.1214	301.4146
P_9	401.8478	394.5147	412.4386
P_{10}	391.2096	398.6383	388.9348
Losses (MW)	81.5879	/	81.7827
F ($/hr)	116420	116400	116386.4652
E(lb/hr)	3932.3	3923.4	3935.9769

From tables 1 and 2, we can see that the economic solution gives the best fuel cost (111498.6581 $) and the environmental solution gives the minimum gas emission (3935.9769 lb).

Table 3
Non-dominant solutions for cost and emission objectives.

Solution	Weight		Objective	
Number	w_1	w_2	Fuel cost($/hr)	Emission (lb/hr)
1	1	0	111498.6581	4584.8366
2	0.9	0.1	111498.8712	4565.0785
3	0.8	0.2	111500.7085	4549.6368
4	0.7	0.3	111510.7057	4528.6489
5	0.6	0.4	111513.2274	4522.9643
6	0.5	0.5	111537.5128	4495.8336
7	0.4	0.6	111542.9312	4491.8964
8	0.3	0.7	111650.7539	4437.8718
9	0.2	0.8	111923.8879	4354.0698
10	0.1	0.9	113622.4424	4106.5212
11	0	1	116369.2736	3934.0322

Table 3 presents the economic and emission solution obtained by the variation of weight factors (w_1 and w_2).

In Simulated Annealing, the best compromise solution can give 111537.5128 $ and 4495.8336 lb when w1= w2= 0.5.

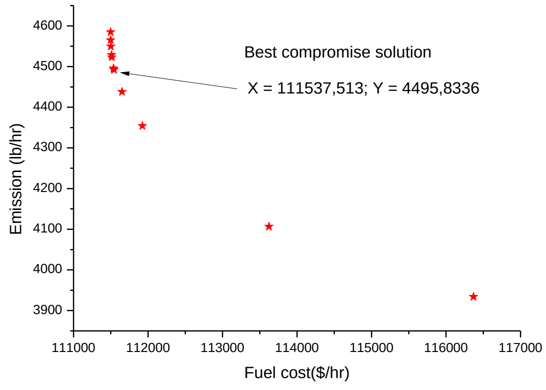

Fig. 5. Pareto optimal front for cost and gas emission objectives.

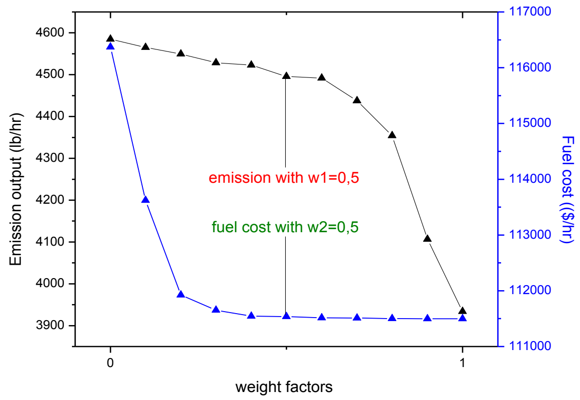

Fig. 6. Fuel cost and gas emission by weight factors variation.

Figure 5 can show the pareto optimal front for fuel cost and gas emission objectives from the economic solution to the environmental solution.

It is seen that for multi-objective economic emission dispatch, the results of power generation are seen in Table IV.

We can see from figure 6 the results of fuel cost and gas emission using the variation of weight factors w_1 and w_2.

Table 4

Power generation dispatch and losses.

Solution Number	Power Generation Dispatch P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	Losses (MW)
1	54.9999	80	107.6263	102.5948	80.7015	81.1210	300	340	470	470	87.0434
2	54.9994	80	110.1485	102.2162	80.7723	78.9268	300	340	470	470	87.0633
3	54.9998	80	101.9164	96.5109	81.5996	91.9722	300	340	470	470	86.9989
4	55.0000	80	102.0713	98.5058	84.0098	87.4237	300	340	470	470	87.0106
5	54.9994	80	100.4357	94.3410	91.0278	86.2215	300	340	470	470	87.0254
6	54.9999	80	98.0852	91.9500	88.3696	93.5923	300	340	470	470	86.9970
7	54.9999	80	90.8588	91.0506	91.1474	98.9049	300	340	470	470	86.9616
8	54.9998	80	93.4393	83.7541	93.6749	101.1218	300	340	470	470	86.9900
9	54.9997	80	85.1886	82.0213	96.3877	113.0614	300	340	470	465.1045	86.7632
10	54.9999	80	84.6924	83.3449	142.4829	144.8856	300	318.3079	427.1209	448.6588	84.4933
11	54.9999	80	76.6331	79.4332	160	240	287.9285	301.4146	412.4386	388.9348	81.7827

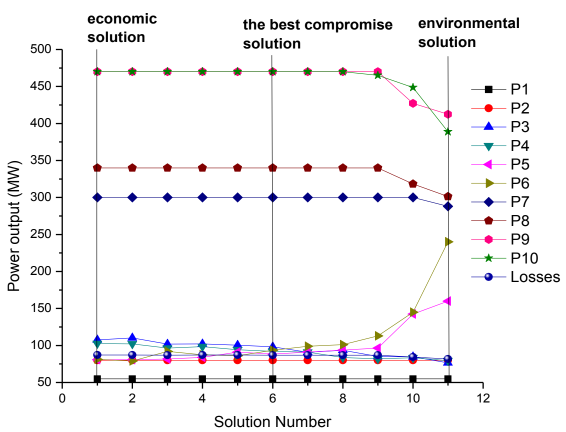

Fig. 7. Power Generation Dispatch by weight factors variation.

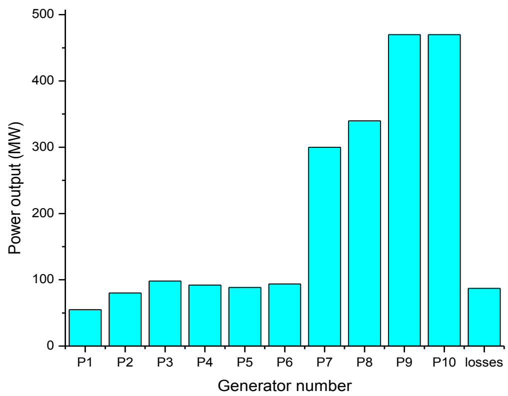

Fig. 8. Power output for each generator with w_1=0.5 and w_2=0.5.

The figure 7 presents the power generation dispatch with losses in 10-unit system by weight factors variation. It is seen that the three vertical lines present the power output for each generator for economic, best compromise and environmental solutions. The figure 8 shows the power output for the all 10 generators when w1=w2=0.5. We can see also that the losses in this system represent 4.16 % from the total power generation.

Conclusion

In this paper, we try to find the optimal solution for minimum fuel cost and minimum gas emission, and give a compromise solution between both the economic and the environmental solutions. SA algorithm is used in this work for determining the multi-objective economic and emission power dispatch problem. The problem is defined as a dual objective optimization problem, to reduce the production cost and emission rate. One system is tested (10 generator system with valve-point effects and transmission losses). The proposed method is compared with other methods (ABC_PSO and DE). Results reveal the effectiveness and usefulness of the simulated annealing method in both aspect of economic and emission dispatch in power systems.

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