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Solving the Generation Scheduling with Cubic Fuel Cost Function using Simulated Annealing

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Abstract

This paper gives the optimal of economic load dispatch when the fuel cost function can be defined as cubic function. The fuel cost is described with 4 parameters. In this work, we use simulated annealing method to find the optimal solution. The SA algorithm is used to minimize the fuel cost and the losses in the power systems. In this study, in order to evaluate the performance of the SA algorithm, it is tested on 2 different unit systems. The results obtained from the proposed method are compared other methods reported previously in the literature. The results show that the SA algorithm is better than the others at solving such a problem.

Keywords: *economic dispatch, cubic fuel cost function, power losses, Simulated Annealing.*

1. Introduction

The cost of electrical production is described with three main sources: facility construction, ownership cost, and operating costs. The operating cost is the most significant of these three, and so the focus will be on the economics of the operation. The solution accuracy of economic dispatch problems is associated with the accuracy of the fuel cost curve parameters. The solution precision of the economic load dispatch is associated with the precision of fuel cost curve parameters. Therefore, updating of these parameters is a very important issue to further improve the final accuracy of economic dispatch problems [1].

The fuel cost function optimizes the total cost of active power generation, assuming that every generator has a convex cost curve related to its own active power, every generator has upper and lower active power generating limits and it is also assumed that the sum of all active powers of generator must be equal to a given total system load plus total system losses. A major challenge for all power utilities is to satisfy the consumer demand for power at minimal cost [2].

To solve the economic load dispatch problems, researchers may use algorithms [3] that terminate in a finite number of steps, Iterative methods [4] that converge to a solution (on some specified class of problems), and heuristics [5] that may provide approximate solutions (A ‘good’ feasible solution) to some problems.

Several strategies such as Genetic Algorithm (GA) [6], [7], Simple Recursive approach [8], Multi-Objective Evolutionary Algorithms(MOEA) [9], Refined Genetic Algorithm (RGA) [10], Particle Swarm Optimization (PSO) [11], Biogeography Based Optimization (BBO)[12], Differential Evolution (DE) [13], Non-Dominated Sorting Genetic Algorithm (NSGA-II) [14], Artificial Bee Colony (ABC) [15], ABC-PSO [16], Gravitational Search Algorithm (GSA) [17] and Parallel Synchronous Particle Swarm Optimization (PSPSO) [18] have been proposed to solve a multi objective dispatch problem.

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2. Mathematical Model of Fuel Cost Curve

Generator cost curves are usually not smooth. However the curves can usually be adequately approximated using piece-wise smooth, functions. So that, the fuel cost curve can be presented as a smooth function. The smooth fuel cost function is defined by polynomial functions as three representations predominate:

- Linear function:

$$F_i(P_i) = a_i + b_i P_i \quad (1)$$

- Quadratic function:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \quad (2)$$

- Cubic function:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 + d_i P_i^3 \quad (3)$$

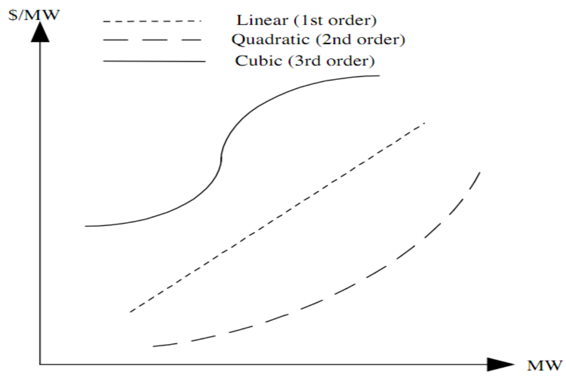

Figure 1. Three Types of Fuel Cost Function Curves

- *Power balance constraints*

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

where P_D is the load demand and P_L is the total transmission network losses.

- *Generator limit Constraints*

Generators have limits on the minimum and maximum amount of power they can produce. Often times the minimum limit is not zero. This represents a limit on the generator's operation with the desired fuel type because of varying system economics usually many generators in a system are operated at their maximum MW limits.

$$P_{i\,min} \le P_i \le P_{i\,max} \quad (5)$$

where $P_{i\,min}$ is the minimum generation limit of unit i and $P_{i\,max}$ is the maximum generation limit of unit i.

- *Power balance constraints*

$$\sum P_i = P_D + P_L \quad (6)$$

where P_D is the load demand and P_L is the total transmission network losses.

The simplest form of loss equation is George's formula, which is given by:

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij} P_i P_j \quad (7)$$

B_{ij} is called the loss coefficient

- *Generator limit Constraints*

The power generation of unit i should be between its minimum and maximum limits.

$$P_{i\,\min} \le P_i \le P_{i\,\max} \quad (8)$$

where $P_{i\,min}$ is the minimum generation limit of unit i and $P_{i\,max}$ is the maximum generation limit of unit *i*.

3. A Simulated Annealing Algorithm for Economic Dispatch Problem

The simulated annealing method [19] is a heuristic optimization technique and it has the ability to find global or near global optimum solutions for large combinatorial optimization problems. This method is similar to the local search technique in optimization, which can only guarantee a local optimum solution. Simulated annealing is proposed in Kirkpatrick, Gelett and Vecchi [20] in 1983 and Cerny [21] in 1985 for finding the global minimum of a cost function that may presses several local minima [22].

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.

$$P_{accept}\{x, y\} = \begin{cases} 1, & if\ E_X - E_Y \le 0 \\ e^{-(E_x - E_y)/k_B T}, & if\ E_X - E_Y > 0 \end{cases} \quad (9)$$

The SA algorithm for dispatch problem is stepped as follows [23]:

Initialization
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).

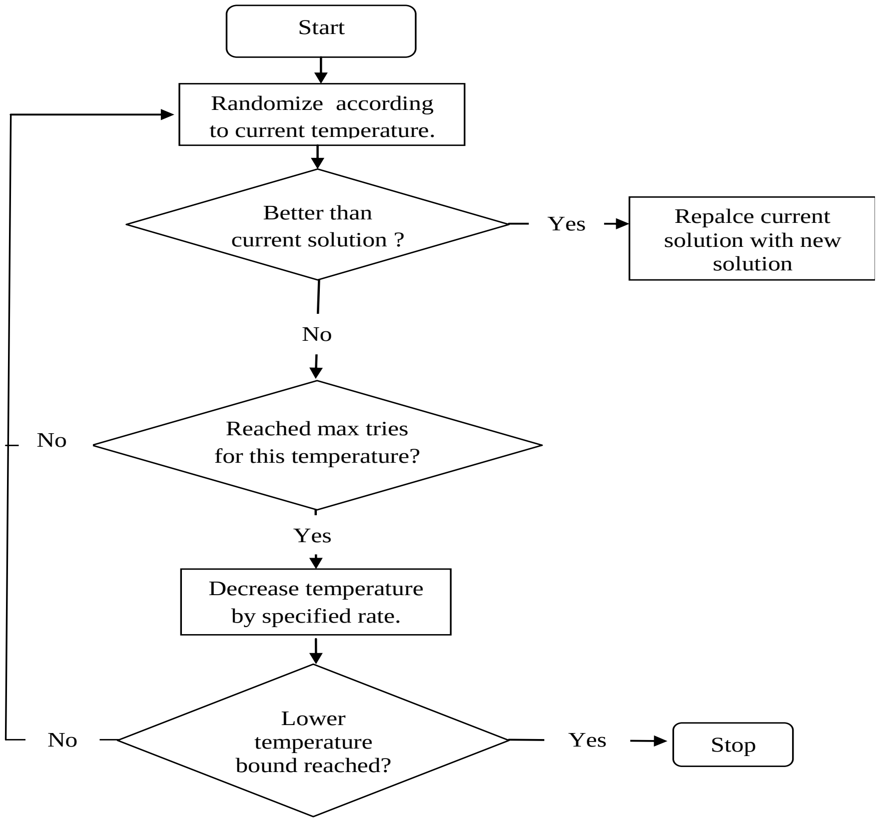

Figure 2. Simulated Annealing Flowchart

4. Results and Discussion

The proposed optimization algorithm is applied to a 2 unit systems to verify its effectiveness. The networks used are Wollenberg's network and Liang's network.

For conducting the test, the initial temperature is fixed at 20 C°, alpha is fixed at 0.4 and max tries is 10000. The final temperature is 1e-10 C°.

4.1. Wollenberg Network Power System

The generator cost coefficients and generation limits of Wollenberg's network are taken from [24] and listed in Table 1. The load demand of this system is 2500 MW.

Table 1. Parameters of Wollenberg's Network System

	a_i	b_i	c_i	d_i	P_{max}	P_{min}
P1	749.55	6.950	0.000968	1.27E-07	800	320
P2	1285	7.051	0.0007375	6.45E-08	1200	300
P3	1531	6.531	0.00104	9.98E-08	1100	275

Table 2. Comparison of Economic Load Dispatch Result of Wollenberg's Network System

	Wollenberg [24]	PRPGA [25]	SA
P1	726.9000	724.991408	725.01284
P2	912.8000	910.153159	910.18417
P3	860.4000	864.855433	864.80299
Demand (MW)	2500.1000	2500.0000	2500.0000
Fuel cost ($/h)	22730.2167	22729.324579	22729.32458

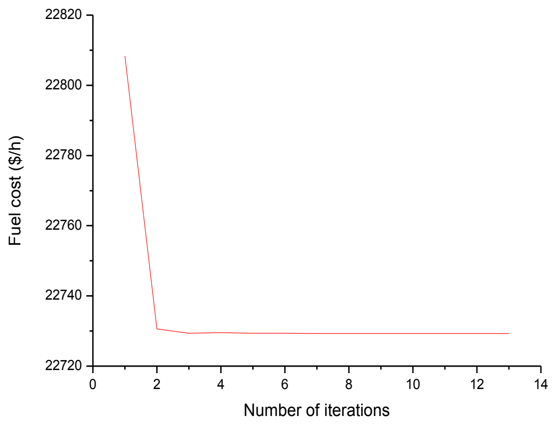

Figure 3. Convergence of Fuel Cost Minimization (Wollenberg's Network System)

The optimal total cost achieved by the proposed SA method is 22729.32458 $/h. The power outputs of generators 1, 2, and 3 are 725.01284 MW, 910.18417 MW, and 864.80299 MW respectively.

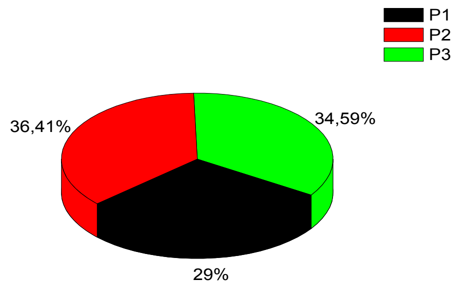

Figure 4. Power percent (%) for each Generator (Wollenberg's Network System)

4.2. Liang's Network Power System

The generator cost coefficients, generation limits and B-coefficients of Liang's network are taken from [26] and listed in table 3 and table 4 respectively. The load demand of this system is 1400 MW.

Table 3. Parameters of Liang's Network System

	a_i	b_i	c_i	d_i	P_{max}	P_{min}
P1	11.2	5.10238	-2.6429e-3	3.33e-06	500	100
P2	-632	13.01	-3.0571e-2	3.33e-05	500	100
P3	147.144	4.28997	3.0845e-4	-1.77e-07	1000	200

Table 4. Bi, J Loss Parameters for Liang's Network System

7.50E-05	5.00E-06	7.50E-06
5.00E-06	1.50E-05	1.00E-05
7.50E-06	1.00E-05	4.50E-05

Table 5. Comparison of Economic Load Dispatch Result of Liang's Network System

	Liang [26]	SA
P1	360.2000	359.7034
P2	406.4000	406.5985
P3	676.8000	677.1375
Demand (MW)	1400	1400
Losses (MW)	43.4000	43.4395
Fuel cost ($/h)	6642.2600	6642.6628

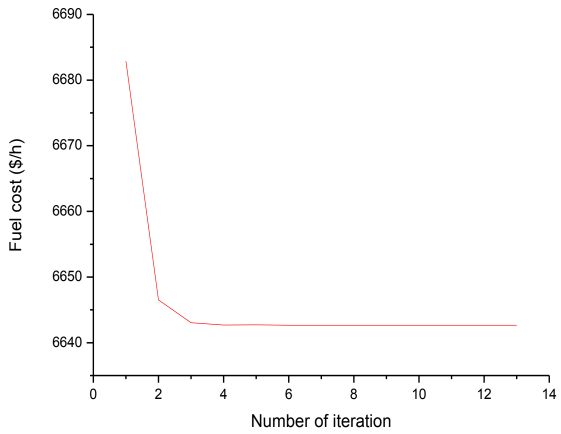

Figure 5. Convergence of Fuel Cost Minimization (Liang's Network System)

The optimal total cost achieved by the proposed SA method is (6642.6628 $). The power outputs of generators 1, 2, and 3 are (359.7034 MW), (406.5985 MW), and (677.1375 MW) respectively. The power losses of this system are (43.4395 MW). Form figures 6 and 7, it can be seen that the power losses present 3.01% from the total power generation.

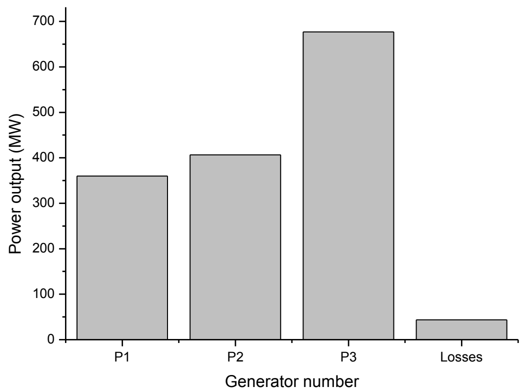

Figure 6. Power Output for each Generator (Liang's Network System)

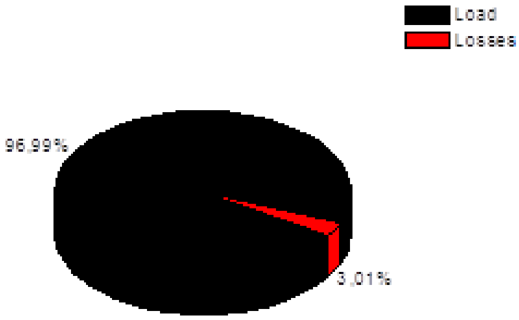

Figure 7. Power Losses Percent (%) (Liang's Network System)

4. Conclusion

A proposed SA method has been developed for solving constrained ELD considering power losses with cubic fuel cost curve. Two test systems are used to validate the proposed method. The studied case has cubic cost characteristics with transmission losses, and comparison is made with other methods in literatures. Based on the simulated results, the proposed SA method provides superior result than previously reported methods. SA algorithm has superior features, including quality of solution and good computational efficiency. The results show that SA is a promising technique for solving complicated problems in power system.

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