Power Dispatch of Hydrothermal Coordination Using Evolutionary Algorithm

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Abstract

This paper is dealing with the solution of the hydrothermal scheduling problem by using evolutionary algorithm. The aim of this study is to minimize the fuel cost and ramping cost of thermal units by utilizing both hydro and thermal units optimally. In evolutionary programming, new generations are produced from randomly generated initial vector by Gauss and Cauchy mutations and they compete with parent vectors and each other. Better individuals are selected for the next generation. The new generation process lasts until either reach to defined iteration number or a minimum function value or the point where developed solutions are no longer different.

1. Introduction

By the hydrothermal scheduling problem, it is aimed to minimize the fuel costs and ramping costs of the thermal units, by utilizing both hydro units and thermal units optimally. Since the objective function is nonlinear, it is required that the objective function express piecewise linear by using Langrange multiplier and gradient method or polynomial approaches. As Sinha says, these linearization let to obtain solutions that are not optimum and let increase in income losses [1]. In latest researches, evolutionary algorithms are used, because they are more efficient and closer to optimum value. Evolutionary algorithms are more flexible and stronger compared to other traditional methods. In this study, evolutionary programming (EP) is used. As Sinha stated, due to using competition and mutation as production and selection method, it shows more performance when it is compared to the other algorithms [1]. In EP, mutation is the only operation to obtain new generation. New generations are generated from parent vectors randomly according to a distribution. In this study, the new generations are generated by both Gauss and Cauchy mutations according to their own distributions. In this study, a hydrothermal scheduling problem is solved by evolutionary programming and its solutions are showed [1-3].

2. Formulation of the Problem

The objective of hydrothermal planning is minimizing the system cost efficiently, by utilizing hydro units, which do not have any fuel costs. Two main factors affect thermal units' costs; fuel costs and ramping costs. For this reason the objective function of the system is expressed as;

$$\min F = \sum_{i=1}^{j} f_i\left(PT_i\right) + RC_i \tag{1}$$

where PT is production of thermal units (MW) and RC is ramping cost ($).

Power dispatch problem can be optimized considering the following constraints.

$$\text{Balance of power demand, } \sum_{i=1}^{6} PT_i + PH = PD_i \tag{2}$$

where PH is production of hydro units (MW) and PD is power demand (MW).

$$\text{Capacity of thermal units, } PT_{min} \le PT \le PT_{max} \tag{3}$$

$$\text{Capacity of hydro units, } PH_{min} \le PH \le PH_{max} \tag{4}$$

$$\text{Change of water volume in the reservoir, } V_{i+1} = V_i - q_j + s_j + r_j \tag{5}$$

$$\text{Initial and final water volume, V(initial)} = V^0 \tag{6}$$

$$\text{V(end)} = V^j \tag{7}$$

Where q is inflow (acre-ft/h), s is spillage rate (acre-ft/h) and q is water discharge (acre-ft/h) if generating.

$$\text{Water discharge limits, } q_{min} \le q_j \le q_{max} \tag{8}$$

$$\text{Water volume limits, } V_{min} \le V_j \le V_{max} \tag{9}$$

Hydro production is a function of water discharge so;

$$PH = PH(q) \tag{10}$$

During ramping process, occurrence condition of ramping cost;

$$RC_i > 0 \ \text{ if } \ RR_i > RER_j \tag{11}$$

where RR is ramp rate of the unit (MW/min) and RER is ramp rate for elastic range (MW/min).

$$\text{V(end)} = V^j \tag{12}$$

When ramping process is included, according to power output the operating cost can be explained as follows [2].

$$C(k) = \int_0^{RT} c(t)dt + \int_{RT}^{1} c(t)dt \tag{13}$$

$$\begin{aligned} C(k) = &\int_0^{RT} (a_0 + a_1(P(k) + RR * t) + a_2(P(k) + RR * t)^2)dt \\ + &\int_{RT}^{1} (a_0 + a_1(P(k) + RR * RT) + a_2(P(k) + RR * RT)^2)dt \end{aligned} \tag{14}$$

where a_0, a_1, a_2 are parameters of objective function.

$$C(k) = (a_0 + a_1 P(k) + a_1 P^2(k)) + R + \tag{15}$$

$$(a_1 + 2a_2 P \ (k)) * (1-(1/2)RT)RT * R + a_2(1-(2/3)RT)RT^2 RR^2$$

$$c_1 = a_0 + a_1 P(k) + a_2 P^2(k) \quad (16)$$

$$c_2 = a_1 + 2a_2 P(k) \quad (17)$$

$$C(k) = c_1 + c_2(1-(1/2)RT)RT * RR + a_2(1-(2/3)RT)RT^2 RR^2 \quad (18)$$

Two main factors affect the life of the rotor; ramping cost and elastic range, which is the threshold for the ramping cost. For example, if the magnitude of power charge is within the elastic range, the ramping process does not shorten the life of the rotor. Ramping costs are incurred when the ramping excursion or change in power output exceeds the elastic range. If the ramping level is within the elastic range, then the cost is zero. Fig. 1 below shows the elastic ranges and ramping costs for different ramping rates. For example, consider a 20 minutes ramping process which results in 90 MW power increase. If the working time is 20 minutes, the ramping cost will be 225 USD. If the working time is 10 minutes, it will results only 45 MW without ramping cost [4-5].

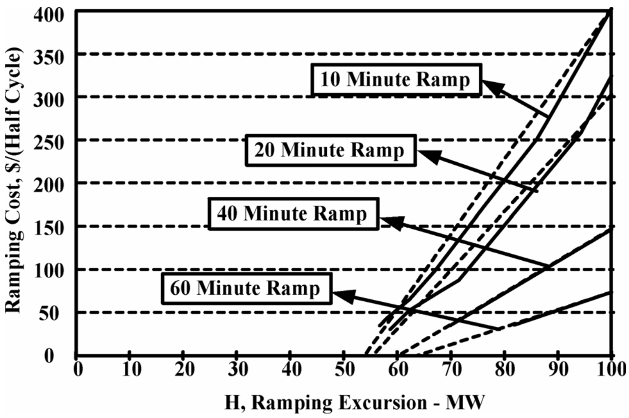

Fig. 1. Ramping Cost Curve for Ramp Periods

As a result, ramping cost is considered to be important both economically and physically. Due to high start up cost, it is uneconomical to start up and shut down the generators. For this reason, this start up and shut down constraints are not used for problems which include ramping costs and this provide life of the rotors to be longer [4-6].

3. Evolutionary Programming for the Hydrothermal Planning

By defining Ip for the population number, every trial vector Qi i=1, 2, 3…, Ip is denoted randomly, from its own component within suitable intervals. A dependent water discharge qd is randomly selected in order to meet the starting and finish reservoir water volume constraint. On the other hand, independent water discharge, qj, j=1, 2, 3, ...,J, where, j is not equal to d (randomly denoted time interval) are stored in J-1 dimensioned vector. In written MATLAB code, d is assumed to be equal to J.

Qi=[q1, q2, q3,..,qJ-1] is i. component of the developed population. J. component of every trial vector is selected randomly within qmin, qmax interval. For simplicity, overflowing is assumed to be zero and discharge is calculated. After calculating discharge, from equation 4, hydro production is calculated, and then by balance of power demand, required thermal power is distributed among thermal units with respect to their fuel costs and possible ramping costs. Thermal costs, constraint violation and possible ramping costs are calculated for population and added to the suitability function.

In this study, new generations are generated by using both Gauss and Cauchy mutations with N(0,1) Gauss distribution and C(0,1) Cauchy variable. Thus, from every vector qj . q1j Gauss mutation and q2j Cauchy mutation are generated from the following equations;

$$q_{1j} = q_j + (\beta \times \frac{Fit_j}{Fit_{min}}(q_{max} - q_{min}))N(0,1) \quad (19)$$

$$q_{2j} = q_j + (\beta \times \frac{Fit_j}{Fit_{min}}(q_{max} - q_{min}))C(0,1) \quad (20)$$

$\beta \times \frac{Fit_j}{Fit_{min}}(q_{max} - q_{min})$ calculates standard deviation for scaling cost, where Fit is the suitability function and β is the scaling constant. The objective function consists of new generated vectors which are sorted in ascending order and best values are selected and compete with the trial vector. The new generation process lasts until either reaching to defined iteration number or minimum function value or the point where developed solutions are no longer different. In this study, the process stopped when it reached to the maximum iteration number.

The developed program consists of two components; main program and production. The flow diagram of the main program is illustrated in Fig. 2. In this part, as explained above, trial vectors and new generation vectors that are produced from trial vectors are generated. This procedure goes on until reaching the fixed iteration number [2-3, 7-11].

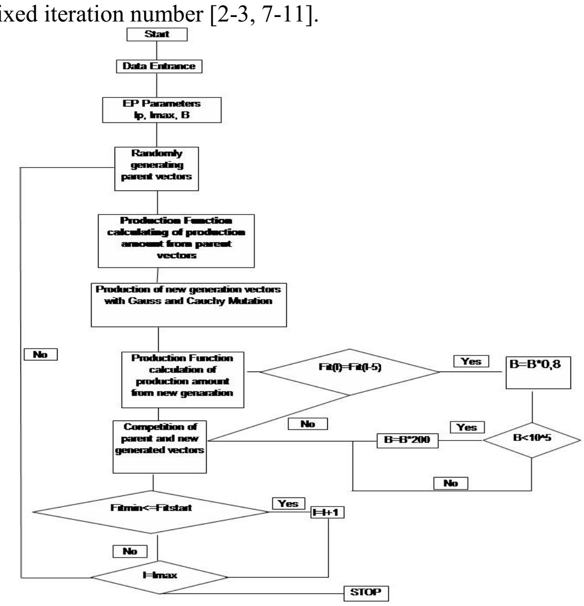

Fig. 2. The flow diagram of the main program

The flow diagram of the production function is illustrated in Fig. 3. In this part, the production variables qd, PTi, PH and Fit are calculated.

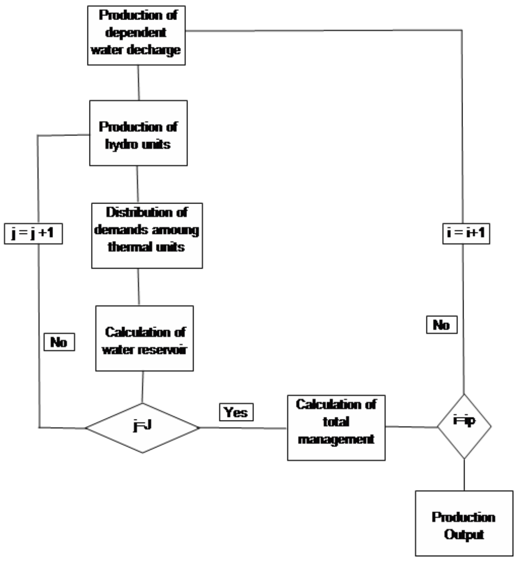

Fig. 3. The flow diagram of the production function

4. Experiment

The input parameters of the problem are following.

Table 1. Capacity limits and ramping information of the thermal units

Thermal Unit	PT min (MW)	PT max (MW)	RR (MW/min)	RT (min)
1	100	500	50	30
2	50	200	25	20
3	80	300	35	25
4	50	150	20	20
5	50	200	25	20
6	50	120	15	15

Table 2. Thermal units fuel costs constants [12]

Thermal Unit	a	a1	a2
1	240	7	0.007
2	200	10	0.0095
3	220	8.5	0.009
4	200	11	0.009
5	220	10.5	0.008
6	190	12	0.0075

Table 3. Other constants

Parameters	Value
Initial water volume	100.000 acre-ft
Final water volume	60.000 acre-ft
Minimum water volume	60.000 acre-ft
Maximum water volume	120.000 acre-ft
Parameters	**Value**
inflow	2.000 acre-ft
Phmin	0 MW
Phmax	1.100 MW
Ip (population size)	60
B (scaling coefficient)	0.03

Table 4. Demands of power generation in a given time interval.

	Power Demand (MW)
1	1200
2	1500
3	1100
4	1800
5	950
6	1300

The solutions of the problem are summarized in Table 5 and Table 6.

Table 5. Power output of units

Power Demand (MW)	Output of PT1 (MW)	Output of PT2 (MW)	Output of PT3 (MW)
1200	304.53	121.81	182.72
1500	304.66	121.86	182.8
1100	305.41	122.17	183.25
1800	304.85	121.94	182.91
950	268.40	107.36	161.04
1300	268.3	107.33	160.99

Power Demand (MW)	Output of PT4 (MW)	Output of PT5 (MW)	Output of PT6 (MW)	Output of PH (MW)
1200	91.36	121.81	73.09	304.66
1500	91.40	121.87	73.12	604.28
1100	91.63	122.17	73.30	202.07
1800	91.46	121.94	73.16	903.73
950	80.52	107.36	64.42	160.90
1300	80.50	107.33	64.40	511.14

Table 6 Production costs of power output

	Power Demand (MW)	Fuel Cost ($)	Ramping Cost ($)	Total Cost ($)
1	1200	61,490.98	3,748.76	65,239.7473
2	1500			
3	1100			
4	1800			
5	950			
6	1300			

The fuel costs and realized ramping costs are shown for each thermal unit in Table 7.

Table 7. Fuel costs and realized ramping costs for each thermal units

	Generating (MW).	Fuel Cost ($)	Ramping Cost ($)	Total Cost ($)
1	304.54	3,020.96	214.11	3,235.07
2	121.81	1,559.12	0.00	1,645.15
3	182.72	2,073.63	137.49	2,211.12
4	91.36	1,280.10	70.56	1,350.65
5	121.81	1,617.77	0.00	1,704.65
6	73.09	1,107.13	43.06	1,150.19

	Generating (MW).	Fuel Cost ($)	Ramping Cost ($)	Total Cost ($)
1	304.67	3,022.42	214.14	3,236.56
2	121.87	1,559.76	0.00	1,645.79
3	182.80	2,074.54	137.50	2,212.05
4	91.40	1,280.59	70.56	1,351.15
5	121.87	1,618.41	0.00	1,705.30
6	73.12	1,107.54	43.06	1,150.60

	Generating (MW).	Fuel Cost ($)	Ramping Cost ($)	Total Cost ($)
1	305.42	3,030.89	214.34	3,245.23
2	122.17	1,563.46	0.00	1,649.54
3	183.25	2,079.86	137.60	2,217.46
4	91.63	1,283.44	70.58	1,354.02
5	122.17	1,622.16	0.00	1,709.08
6	73.30	1,109.90	43.07	1,152.97

After 700 iterations, the convergence scaling is shown Fig 4. In order to meet the demands, the optimum cost is calculated as 65,239.74 $.

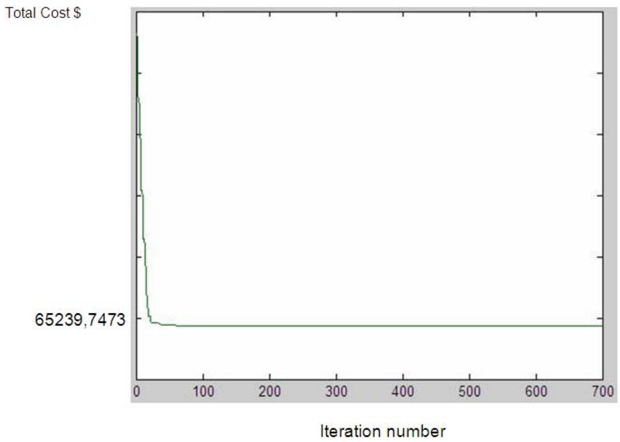

Fig. 4. The change of total cost in terms of iteration number

5. Conclusions

In this study, hydrothermal scheduling problem was solved with a developed evolutionary program. Convergence graph shows programs' convergence success and also program has reached to a value which is more close to the optimum faster because of usage of deterministic competition rather than stochastic competition. In this study, deterministic competition is used, which means that from every parent vector and their generation, the fuel and ramping costs are calculated and these Ip solutions are sorted in ascending order. The first vector is selected and the program continues the process until the system reaches to the finishing conditions. Due to high start-up costs, it is not economical to start up and shut down frequently. Since the objective of generation scheduling in this study contains the start up and ramping costs, the unit on/off states can be determined economically by this method. So it is not necessary to have the min-times as constraints [4]. In conclusion, the hydrothermal problem is solved with evolutionary algorithms and systems management costs containing fuel costs and ramping costs are showed above and its convergence success confirm in the convergence graph.

6. References

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