Engineering EEE

Evolutionary Programming Solution For Economic Dispatch Of Units With Ramp Rate Limits

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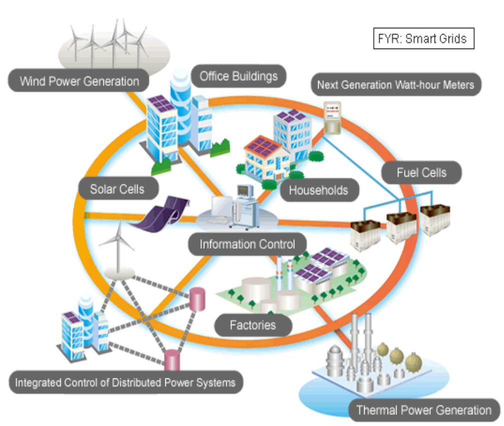
GRAPHICAL ABSTRACT



ABSTRACT

This paper presents a new approach using evolutionary programming for solving the economic dispatch problem of generators when all of the units have ramp characteristics. The use of ramp-rate constraints to simulate the unit state and generation changes is an effective and acceptable approach in the view of theoretical developments of industrial processes. Since implementing ramp-rate constraints is a dynamic processes. The proposed method is implemented for solving a few example dispatch problems. The results obtained by this new approach are compared with those obtained using traditional methods. The study results have shown that the approach developed is feasible and efficient.

Keywords: Dynamic economic dispatch, Power balance constraint, Capacity limit constraint, Evolutionary Programming, Ramp rate limits

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I. INTRODUCTION

The economic dispatch problem assumes that the amount of power to be supplied by a given set of units is constant for a given interval of time and attempts to minimize the cost of supplying this energy subject to constraints on the static behavior of the generating units [1] [2]. However, plant operators, to avoid shortening the life of their equipment, try to keep thermal gradients inside the turbine within safe limits. This mechanical constraint is usually translated into a limit on the rate on increase/decrease of the power output. Such ramp rate constraints distinguish the dynamic economic dispatch from the traditional static economic dispatch [3] [4]. Since these ramp rate constraints involve the evolution of the output of the generators, the dynamic economic dispatch cannot be solved for a single value of the load. Instead it attempts to minimize the cost of producing a given profile of demand [5] [6].

The dynamic economic dispatch is one of the main functions of power system operation and control. It is a method to schedule the online generator outputs with the predicted load demands over a certain period of time so as to operate an electric power system most economically while the system is operating within its security limits [7] [8].

Since dynamic economic dispatch was introduced, several optimization techniques such as Simulated Annealing (SA), Genetic Algorithm (GA) and Evolutionary Programming (EP) have been given much attention by many researchers due to their ability to seek for the near global optimal solution. The SA technique has been applied in many power system problems. However, appropriate setting of the control parameter of the SA based algorithm is a difficult task and the speed of the algorithm is slow when applied to a real power system [9] [10]. Both GA and EP can provide a near global solution. But the encoding and decoding schemes essential in the GA approach are not needed in dynamic economic dispatch problem. The EP, therefore, is faster in speed than GA in DED case.

II PROBLEM FORMULATION

The objective of ED is to determine the generation levels for all on-line units which minimize the total fuel cost, while satisfying a set of constraints.
It can be formulated as follows:

A. Objective function :

The fuel cost functions of the generating units are usually described by a quadratic function of power output P_i as:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \qquad (1)$$

Where, a_i , b_i and c_i *are the* cost co-efficient of unit *i*.
The objective is to minimize the cost function

$$\min F = \sum_{i=1}^{N} F_i(P_i) \qquad (2)$$

Where N is the number of generating units.
F_i (P_i) is the individual fuel cost function of i^{th} generating units.

B. Power balance constraint :

The total real power generation meets the total load demand which is best represented by equation (3),

$$\sum_{i=1}^{N} P_{ih} = P_{dh} \qquad h = 1, 2, \ldots, H \qquad (3)$$

where
P_{dh} is the load demand at hour *h*
P_{ih} is the power output of i^{th} generating unit at hour *h*.

C. Capacity limit constraint:

The lower and upper bounds of real power output generated per hour is represented by equation (4),

$$P_i^{\min} \le P_{ih} \le P_i^{\max}, \quad i = 1, 2, \ldots, N \quad h = 1, 2, \ldots, H \qquad (4)$$

where
$P_i^{\min}$ is the minimum power generation limit of the i^{th} generator
$P_i^{\max}$ is the maximum power generation limit of the i^{th} generator.

D. Ramp rate constraint:

The ramp-up and ramp-down rate limits of i^{th} generator in MW/hour are given by [8]

i) as generation increases

$$P_{ih} - P_{ih}^{0} \le UR_i \qquad i=1,2,\ldots N \quad h=1,2,\ldots\ldots H \qquad (5)$$

ii) as generation decreases

$$P_{ih}^{0} - P_{ih} \le DR_i \qquad i=1,2,\ldots N \quad h=1,2,\ldots\ldots H \qquad (6)$$

where
UR_i and DR_i are the ramp-up and ramp-down rate limits of i^{th} generator respectively.
P_{ih} is the output power of unit *i* at current hour
P_{ih}^{0} is the output power of unit *i* at previous hour.

III. EP BASED DED ALGORITHM

A. Representation

For T intervals in the generation scheduling horizon, there are T dispatched for the N generating units. For the N generating units, control variables of this problem are the generating output from all units. An array of these control variable vector can be shown as

$$S = \begin{bmatrix} P_{11}\ P_{12}\ldots\ldots\ldots P_{1T} \\ P_{21}\ P_{22}\ldots\ldots\ldots P_{2T} \\ \\ P_{N1}\ P_{N2}\ldots\ldots\ldots P_{NT} \end{bmatrix} \qquad (7)$$

B. Initialization

To begin, population of chromosome is uniform randomly initialized within the operation range of the generator.

C. *Fitness evaluation*

The active power generations at all buses in all intervals are control variable, which are self constrained. Equality constraint in equation (3) can be handling by using

$$if \sum_{i=1}^{N} P_{it} > P_{Dt}, then\ P_{it}^{new} = P_{it}^{old} - \frac{\sum_{i=1}^{N} P_{it}^{old} - P_{Dt}}{N} \qquad (8)$$

$$if \sum_{i=1}^{N} P_{it} < P_{Dt}, then\ P_{it}^{new} = P_{it}^{old} + \frac{P_{Dt} - \sum_{i=1}^{N} P_{it}^{old}}{N} \qquad (9)$$

The operating ramp rate constraints are handled by adding them as the exact penalty terms to the objective function to form a generalized objective function as

$$\min \sum_{i=1}^{T} \sum_{i=1}^{N} F_{it}(P_{it}) + \sum_{i=2}^{T} \sum_{i=1}^{N} P_r \left| P_{it} - P_{r\lim} \right| \qquad (10)$$

Where
P_r is penalty parameter
P_{rlim} is defined by

$$P_{r\lim} = \begin{bmatrix} P_{i(t-1)} - DR_i\ if\ P_{it} < P_{i(t-1)} - DR_i \\ P_{i(t-1)} + UR_i\ if\ P_{it} > P_{i(t-1)} + UR_i \\ P_{it}, \qquad otherwise \end{bmatrix} \qquad (11)$$

Here the value of generalized objective function is used to indicate the fitness of the candidate solution of each individual.

D. Creation of offspring

Offspring is produced from the existing population by adding a Gaussian random number with zero mean and a predefine standard deviation to each individual as

$$P_{it}^{'} = P_{it} + N(0, \sigma_{it}^{2}) \qquad (12)$$

σ_{it} *is calculated from*

$$\sigma_{it} = \beta \times \frac{f_s}{f_{\min}} (P_{it,\max} - P_{it,\min})$$

where, β *is a scaling factor*

f_s *is the fitness value of the* s^{th} *individual*

$f_{\min}$ *is the minimum fitness among the P parents*

After adding a Gaussian random number to parents, the elements of offspring may violate constraints given by eqn.3, these violations are dealt with

$$P'_{it} = P_{it,\min} \; if \; P'_{it} < P_{it,\min}$$
$$P'_{it} = P_{it,\max} \; if \; P'_{it} > P_{it,\max} \qquad (13)$$

E. Selection and competition

The selection technique used here is the stochastic tournament method. The 2P individuals compete with each other for selection. A weight value W_s is assigned to each individual as follows:

$$W_S = \sum_{j=1}^{P} W_j$$
$$W_j = 1 \;\; if \;\; f_S < f_r \qquad (14)$$
$$W_j = 0, \quad otherwise$$

Where, f_r *is the fitness of the* r^{th} *competitor randomly selected from 2P individuals*

IV.SIMULATION RESULTS AND DISCUSSION

Solutions for dynamic economic dispatch problem were obtained for ten units system with quadratic fuel cost functions are shown in Table 1. The dynamic economic dispatch problem has been solved by conventional linear programming and evolutionary programming methods. To determine the effectiveness, the conventional method compared with the evolutionary programming method. The evolutionary programming method was found to be better in solving the dynamic economic dispatch problem. The comparisons results of EP and LP are also shown in Table 2. From that, the result obtained from EP was better than those obtained from LP. Simulations were carried out and obtained the average total production cost and computed time from 10runs with scaling factor 0.005, maximum generation 10000 while varied the population size from 20 to 80.

Table 1 Solution for Ten Unit systems

U/T	1	2	3	4	5	6	7	8	9	10	11	12
1	238.7	243.0	261.4	262.1	281.0	286.2	282.0	260.0	250.1	235.6	249.5	256.9
2	357.2	365.5	382.8	387.8	407.5	407.5	405.3	383.5	369.7	358.0	375.9	377.1
3	414.8	418.6	442.8	439.7	459.7	470.3	463.2	438.8	426.4	415.4	425.3	433.8
4	477.1	481.7	505.2	506.0	530.4	540.0	530.4	506.4	488.3	473.5	490.9	501.8
5	418.2	421.6	443.7	444.6	461.3	469.1	467.8	439.0	427.3	409.7	425.2	431.4
6	549.7	559.0	581.6	588.6	625.3	634.8	626.0	581.8	564.6	550.3	573.5	583.0
7	619.0	620.0	620.0	620.0	620.0	620.0	620.0	620.0	620.0	619.9	620.0	620.0
8	643.0	643.0	643.0	643.0	643.0	643.0	643.0	643.0	643.0	643.0	643.0	643.0
9	899.2	916.6	920.0	920.0	920.0	920.0	920.0	920.0	920.0	901.1	920.0	919.9
10	943.1	951.0	995.5	998.1	1041.9	1049.1	1042.3	997.5	970.7	933.4	968.8	983.1
$	173398	176060	184201	184660	193059	195435	193531	183742	178745	172517	179199	181915

Table 2 Comparison of Simulation results

Method	Cost($)
Linear Programming	2196939
Evolutionary Programming	2196462

CONCLUSION

This paper has presented a new approach using EP for solving dynamic economic dispatch problem when all of the units have ramp characteristics. The versatility of the method in handling any number of constraints has also been shown by taking into account of power balance constraint and unit capacity constraint. The proposed method has been tested with example problems on economic dispatch and their results have been compared with those obtained by traditional method. The results obtained show that the proposed method is simple, reliable and efficient and has great potential for solving practical economic dispatch problems.

APPENDIX

Unit Data of Ten Unit Systems

	P_{min} (MW)	P_{max} (MW)	a ($/h)	b ($/MWh)	c ($/MW^{2}h)	UR (MW/h)	DR (MW/h)
Unit 1	155	360	180	26.4408	0.03720	20	25
Unit 2	320	680	275	21.0771	0.03256	20	25
Unit 3	323	718	352	18.6626	0.03102	50	50
Unit 4	275	680	792	16.8894	0.02871	50	50
Unit 5	230	600	440	17.3998	0.03223	50	50
Unit 6	350	748	348	21.6180	0.02064	50	50
Unit 7	220	620	588	15.1716	0.02268	100	100
Unit 8	225	643	984	14.5632	0.01776	100	150
Unit 9	350	920	1260	14.3448	0.01644	100	150
Unit 10	450	1050	1200	13.5420	0.01620	100	150

REFERENCES

[1] A.J.Wood and B.F.Wollenberg, power generation operation and control, 2nd edition, New York: Willey 1996.

[2] B. H. Chowdhury and S. Rahman, “AReview of Recent Advances In EconomicDispatch”,IEEE Transactions on Power Systems, vol. 5, no. 4, pp. 1248-1259, November 1990.

[3] Y. H. Song and I. K. Yu, “Dynamic load dispatch with voltage security and Environmental

constraints," Electric Power Systems Research, vol. 43, no. 1, pp. 53-60, October 1997.

[4] R. W. Ferrero and S. M. Shahidehpour, "Dynamic economic dispatch in deregulated systems," International Journal of Electrical Power and Energy Systems, vol. 19, no. 7, pp. 433-439, October 1997.

[5] P. Attaviriyanupap, H. Kita, E. Tanaka and J. Hasegawa, "Dynamic economic dispatch using evolutionary programming combine with sequential quadratic programming", Proceeding of Intelligent System Application to Power Systems Conference, pp. 137-141, June 2001.

[6] Han, X.S., Gooi, H.B., Kirschen, D.S., "Dynamic economic dispatch: feasible and optimal Solutions", *IEEE Transactions on Power systems*, vol. 16, no. 1, pp. 22-30, 2001.

[7]Wood, W.G., "Spinning reserveconstraint static and dynamic economic dispatch", *IEEE Transactions on Power apparatus and systems*, vol. 101, no. 2, pp. 381-388, 1982.

[8] Li, F., Morgan, R., Williams, D., "Hybrid genetic approaches to ramping rate constrained dynamic economic dispatch", *Electric Power System Research*, vol. 43, no.2, pp. 97- 103, 1997.

[9]Panigrahi, C.K., Chattopadhyay, P.K., Chakrabarti, R.N., *et al*., "Simulated annealing technique for dynamic economic dispatch", *Electric Power Component Systems*, vol. 34, no.5, pp. 577-586, 2006.

[10] R. Chattopadhyay P.K., Basu, M., *et al*., "Particle swarm optimization technique for dynamic economic dispatch", *IE (I)*, Vol. 87, pp. 48-54, 2006.

BIOGRAPHIES

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